Optimal Cavity Wall Insulation Study for Projected Climates and Energy Trends in UK

by

Vagelis Giouvanos

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ABSTRACT

The purpose of this study was to examine if the optimal insulation will still be considered optimal in terms of energy and mostly carbon emissions if we take into account the climate change and the change in the fuel mix that is used for domestic space heating. During the assumed lifetime of the building (100y) different climate change scenarios and fuel mix compositions were modelled and the overall carbon emissions for this period were calculated. For each different combination an optimal insulation thickness was sought. The results were analysed to understand how important, future climate change and projected fuel mix are, in choosing the current optimum insulation thickness. Though some important observations were made, there was a marginal effect in insulation thickness compared to other studies that hadn't taken them into account.

Acknowledgements

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Foremost my parents and sister and especially my mother who is always on my side

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1. INTRODUCTION

1.1 Preface

Energy is one of the most important environmental issues of our times. The increasing global energy demands are mostly supplied by fossil fuels, which are not only finite but also release carbon dioxide (CO_2) when burnt. CO_2 is one of the primary "greenhouse gases" (GHG's) that is considered responsible for global warming and climate change.

The Kyoto protocol (1997) was an attempt to alleviate projected climate changes by assigning mandatory targets for reduction of greenhouse gases to participant nations. The UK's commitment is to cut down greenhouse gases by 12.5% in the period 2008-2012. The UK Climate Change Programme that was launched in 2000 went beyond that, committing to cut down CO_2 emissions by 20% by the year 2010[1] compared to the 1990 base year levels. Furthermore in the Energy White Paper (2003) the government committed to a 60% reduction in CO_2 emissions by the year 2050.

Energy consumption in buildings are one of UK's fastest growing CO_2-emitting sources, so energy efficiency and sustainable development in this sector are crucial in achieving the set targets.

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1 Climate Change, The UK Programme 2006, TSO, 2006

1.2 The role of insulation

Space heating energy accounts for almost a third of the total energy use in UK. One of the most important aspects determining the amount of energy used for space heating is the building envelope's insulation[2].

A lot of research has been aimed at finding the optimal thickness for wall insulation. Energy analysis of building performance was initially a reaction to the oil crisis of the seventies, but has continued to gain significance due to climate change trends, specifically global warming. Early studies mainly dealt with the economic aspects of energy. However, since it became clear that anthropogenic greenhouse gas emissions were partly responsible for global warming [3], the analysis shifted towards a more environmental approach.

The purpose of energy analysis became mitigating climate change, so the reduction of CO_2 emissions that result from buildings' life-time performance is an essential part of the studies.

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2 Shorrock L D, J I Utley J I, Domestic Energy Fact file, BR 457, BREPress, 2003
3 IPCC, 2001: Climate Change 2001: Synthesis Report. Third Assessment Report of the IPCC, Cambridge 2001

2. WORK TO DATE

2.1 Building regulations

Many studies have been undertaken trying to find the optimal wall insulation thickness. Although the findings of these studies were assessed and taken into account by policymakers whenever building regulations were revised, the prescribed insulation thickness was never implemented into the new legislation. The reason for this is that policy making is normally a compromise between different interests. The legislating bodies have to balance the advantages in CO_2 emission reductions against the increased costs resulting from required quantities of insulation. Furthermore, there are technical limitations that have to be taken into consideration. Most important are local builders' competence and experience for constructing a heavily insulated building. Nevertheless, the building regulations progressively prescribed lower U-values over the years.

U-values were first introduced, for walls, in 1965 when the upper limit was 1.7W/m^{2}K. Following the oil crisis (1973/74), in 1976 the U-value was tightened to 1.0 W/m^{2}K and became 0.6 W/m^{2}K by 1985. A further reduction in 1990 made the requirement 0.45 W/m^{2}K. The 1990 amended U-values, together with the introduction of a requirement for the ratio of window area/ floor area to be less than 15%, were expected to result in a 20% reduction in energy use for space heating. The actual figure might be less, even as low as 6%[4]. In 1995 the U-values of external walls and ground floors remained the same but those for semi-exposed walls and floors were reduced and implemented respectively to a target of 0.6 W/m^{2}K. The window-to-floor area ratio was raised to 22.5%. The 2002 regulations reduced U-values again bringing the figure for external walls to 0.35 W/m^{2}K and 0.25 W/m^{2}K for floors (Table 1). Additional external elements, namely doors and windows, were subject to control, while a distinction in the types and constructions of roofs was introduced.

[4] Johnson JA, Building Regulations Research Project,2003

	Year of Regulation					
Element	1976	1985	1991	1995	2002	2006
Ground	1.00	0.60	0.45	0.35	0.25	0.25
Roof	0.60	0.35	0.20	0.20	0.20	0.20
Walls	1.00	0.60	0.45	0.45	0.35	0.35
Windows	N/a	5.70	5.70	3.00	2.2	2.2

Table 1: Historic and current elemental maximum U-values in building regulations

The new building regulations that came into effect on April 6th 2006 kept the same limits for insulation (i.e. U-values), though the role of SAP 2005 was upgraded and required that the DER (dwelling emission rate), which is the predicted rate of CO_2 dwelling emissions, is not greater than the TER, target emission rate[5].

Still the insulation standards in the UK are lower than those of some European countries, while the number of heating degree-days is higher than some (Table 2). This can be seen in Table 2 where the UK's insulation standards are compared with the best available and in Figure 1 where the insulation thickness in new buildings is compared among European countries.

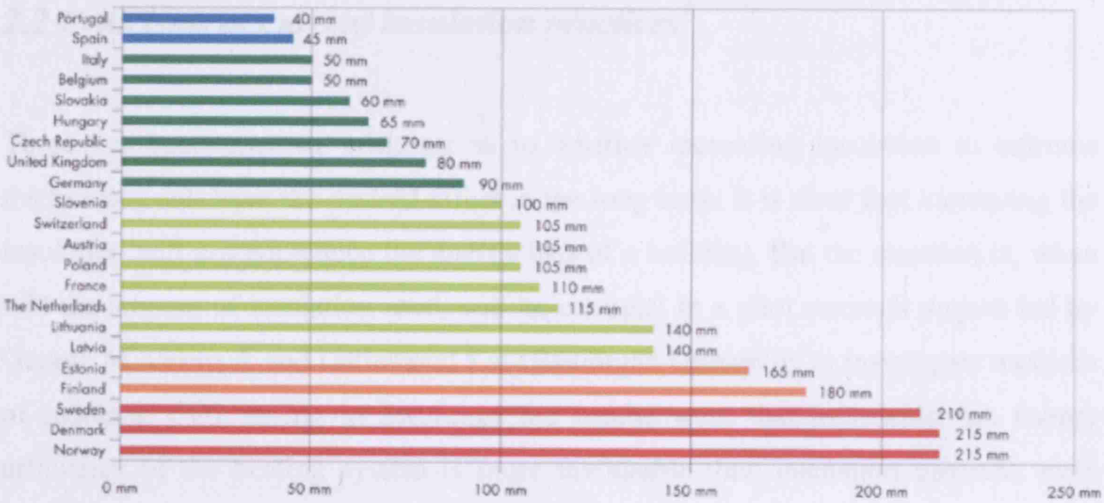

Figure 1: Wall thickness insulation for new dwellings in European countries.
{Source: European insulation Manufacturers Association, available online [http://www.eurima.org/facts_figures/insulation_thickness.html][accessed September 2006]}

[5] Conservation of fuel and power, Approved Document L1A, 2006

Product	Source of best standard	Best standard	UK standard
Roof U value.	Sweden.	0.12 W/m^2K.	0.25 W/m^2K (E&W) 0.20 W/m^2K Scotland. 0.25 W/m^2K NI.8
External wall U value.	Sweden.	0.17 W/m^2K.	0.35 W/m^2K E&W. 0.30 W/m^2K Scotland. 0.45 W/m^2K NI.
Ground floor U value.	Sweden.	0.15 W/m^2K.	0.25 W/m^2K E&W and Scotland 0.45 W/m^2K.NI
Windows U value.	Sweden and Norway.	1.3 W/m^2K.	2.2 W/m^2K E&W and Scotland 3.3 W/m^2K NI.
Air leakage.	Sweden.	<2 air changes per hour at 50 Pa pressure.	<10 air changes per hour at 50 Pa pressure E&W.

Table 2: Comparison of best insulation in building standard with UK building Regulation standards. [6]

(SOURCE: Comparison of UK and Best international Standards as of March 2006, Report for Defra by the Market Transformation Programme, 2006)

2.2 Criticisms of current insulation practices[7]

There has been growing criticism as to whether increasing insulation to extreme thicknesses will have the desired effect in the long term. It is clear that increasing the insulation will always reduce the energy loss of a building. But the question is, when will the amount of insulation used, will be enough? In a pilot research project led by George M, Geens A and Littlewood J at Glamorgan University to investigate methods of reducing CO2 saving in dwellings the results were that increasing the energy efficiency of the heating system is more favourable than insulation upgrade, even nominal in the case of insulating solid floors. The authors made a contribution to the

[6] (This is based on a limited comparison of only six countries within Europe and two states in the USA.)

[7] http://en.wikipedia.org/wiki/Energy_efficiency_in_British_housing [accessed 21 August 2006]

ODPM consultation process stating that insulation levels have reached and in some situations, exceeded their optimum level for dwellings that are not designed for zero heating[8,9].

After the 2006 Building Regulations doubts where raised as to whether these changes will result in a 20% cut-back in emissions. In a study carried in 2005 sponsored by the Pilkington Energy Efficiency Trust the savings where predicted to be around 9% compared to those that were built at that time.

Despite the tightening of the regulations, there are still strong criticisms by some about the regulations failing to go even further.

Another aspect that has to be investigated thoroughly is that not only the embodied energy of the insulation that has to be accounted in an energy analysis. One must also consider the fact that wider insulation thicknesses will require corresponding increases in the foundation width and additional energy for the excavation, transportation and additional building materials to reach the same gross floor area.

2.3 Optimal insulation thickness

It is not arguable that increasing insulation will result in reductions in energy use for space heating and cooling. Still there are theoretical limits to such savings.

"Energy Analysis and Optimal Insulation Thickness"[10] which was presented in Paris during the International Conference on Building and Environment, on which this paper is expanding on, quantified and gave numerical answers to the problem.

According to the authors, optimal insulation thickness in a cavity construction wall would be 450mm if it was optimised for energy use and 340mm if it was optimised for CO_2 emissions. The amount of insulation was and still is surprisingly higher than that required by UK building regulations. For example using the same kind of insulation (i.e. mineral wool) to achieve the U-value of 0.35 for external walls that are today's worst acceptable level will require a thickness of around 80mm in a cavity construction wall which is 4 to 6 times lower than those calculated above.

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[8] Building for a future, Winter 2005/6

[9] ODMP,2004, Proposals for amending Part L

[10] Lowe et al, 1997

2.5 Energy Consumption for Space Heating

Around 30% of the 1,186 TWh/y of total non-transport energy services consumed in the UK is in the form of heat for space and process heating. The carbon emissions related to that energy are close to 30% of the total UK emissions. The rises in percentage from the 1990 figures are mainly because of the substantial decrease in industry's CO2 emissions. Apart from mild fluctuations the emissions have remained around 40 million tonnes of carbon equivalent since 1990[11] when the first tighten building regulations where put in effect.

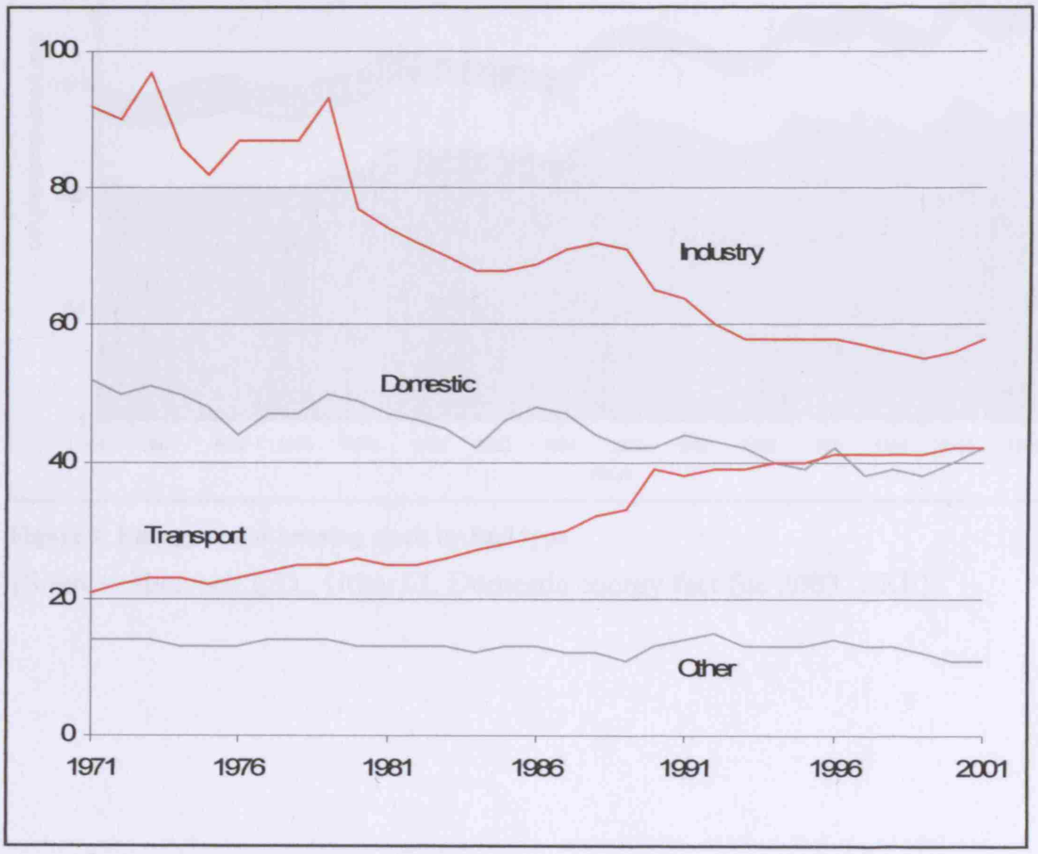

Figure 2: Emissions of carbon dioxide: by end user (million tonnes of carbon equivalent)

Source: National Environmental Technology Centre

The main reasons why domestic carbon emissions were at a steady decline from 1970 till the early 1990 where i) improved insulation standards, ii) heating system

[11] Emissions of carbon dioxide: by end user: Social Trends34, Online version, http://www.statistics.gov.uk/StatBase/ssdataset.asp?vlnk=7280&Pos=&ColRank=1&Rank=272 {accessed 21 August 2006}

efficiency iii) changes to the electricity supply industry and iv) alterations in the fuel mix of the domestic sector [12].

Delivered energy has however risen, see Figure 3, whereas overall carbon emissions have fallen (Figure 4) due to the increase in natural gas as it became the preferred fuel, since it has fewer emissions and is a cleaner fuel than coal or oil.

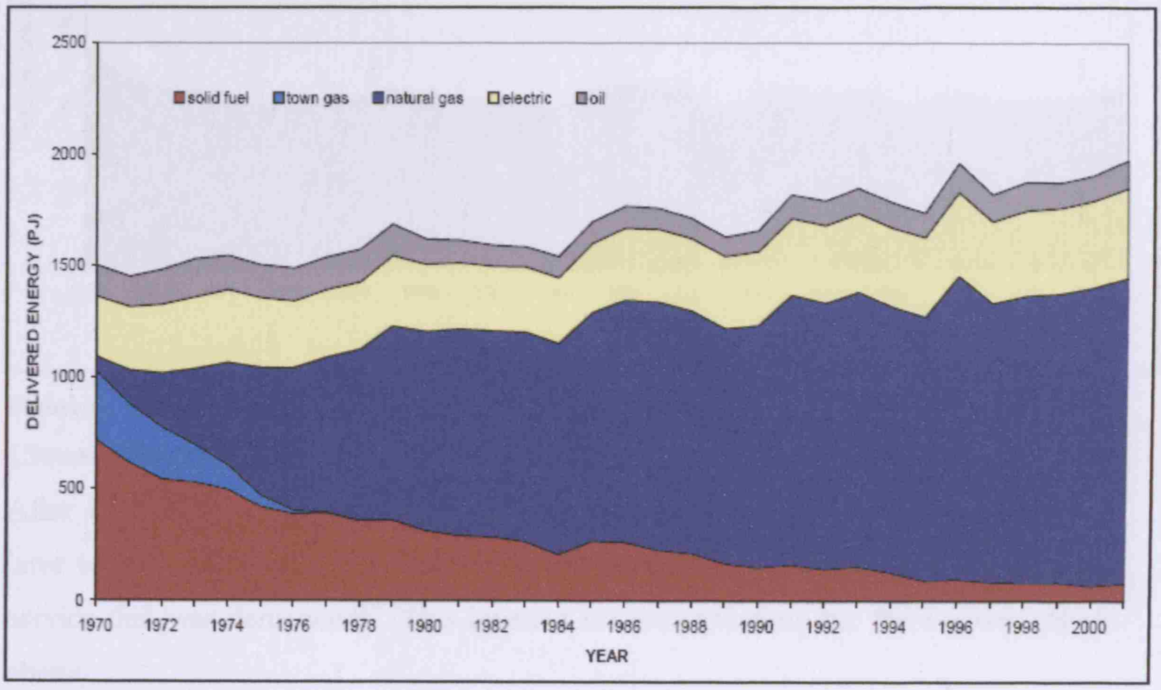

Figure 3: Energy use of housing stock by fuel type

{Source: Shorrock L.D., Utley J.I, Domestic energy fact file 2003, BRE}

[12] Shorrock L., A detailed analysis of the historical role of energy efficiency in reducing carbon emissions from the UK housing stock, 2003, ECEEE

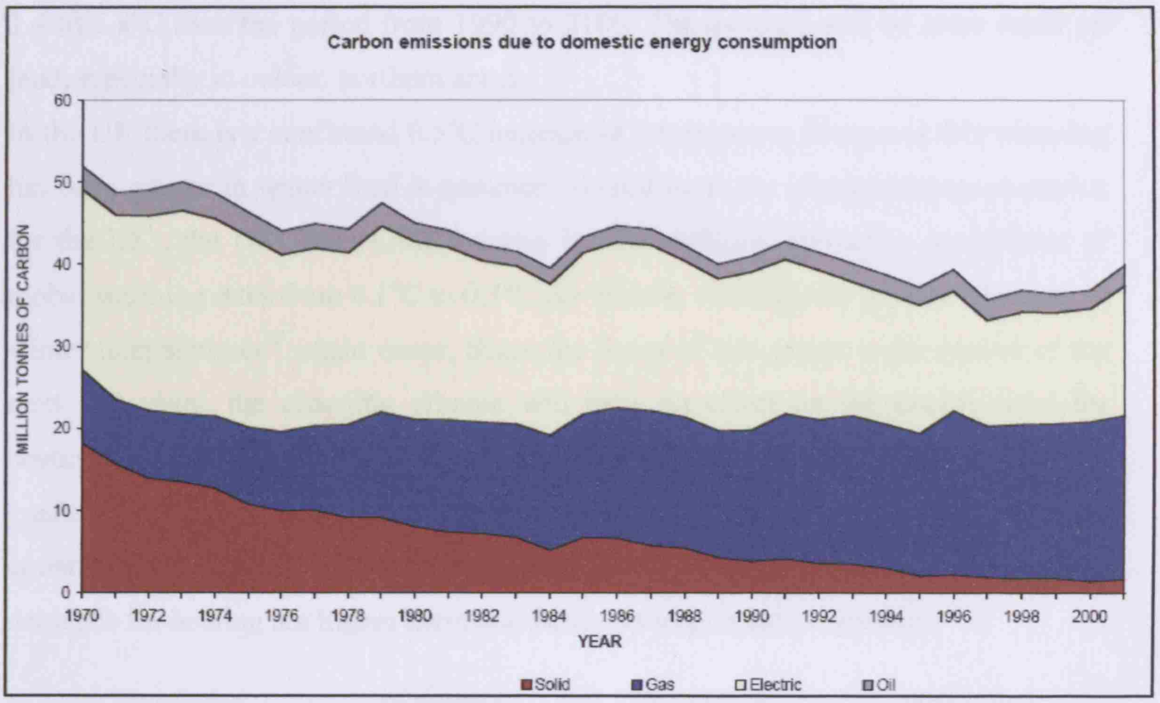

Figure 4: Carbon emissions due to domestic energy consumption

{Source: Shorrock L.D., Utley J.I, Domestic energy fact file 2003, BRE}

After 1990 when there was a mild fluctuation in the domestic sector's emissions we have to take into account the increase in the number of households and the level of service that was demanded[13]. This levelled off the reduction due the reasons stated above.

Around 60% of domestic energy consumption is attributed to space heating and this percentage had a small increase from 1990 (58%)[14].

2.5 Climate change

The average surface temperature of the planet has increased by about 0.6°C (+/-0.2°C) in the 20th century. The period 1972-2000 is one of the times when most warming has occurred according to IPCC's Third Assessment Report on Climate Change (2001). Furthermore, under all the scenarios that were modelled global average temperature will continue to rise in the 21st century and temperatures are projected to increase by

[13] Shorrock L., A detailed analysis of the historical role of energy efficiency in reducing carbon emissions from the UK housing stock, 2003, ECEEE

[14] DTI estimates from data supplied by the Building Research Establishment

1.4 to 5.8°C over the period from 1990 to 2100. The increase will be more rapid on land, especially in colder, northern areas.

In the UK there is a confirmed 0.5°C increase in temperature. Moreover this warming has been greater in winter than in summer. According to the climate change scenarios for the UK,, the UKCIP02 (2002) shows in four different scenarios, projections of global warming rates from 0.1°C to 0.3°C per decade, with slightly greater warming in winter than summer[15] might occur. Since the focus of this report is the period of the next 100 years, the changing climate will have an effect on the energy used for heating. The number of heating degree days is expected to decrease substantially and gradually by 2080. Reductions will be, in absolute values, uniform all over the country but relatively higher over Scotland and Northern England. The energy demands for heating are higher there and hence its importance is greater.

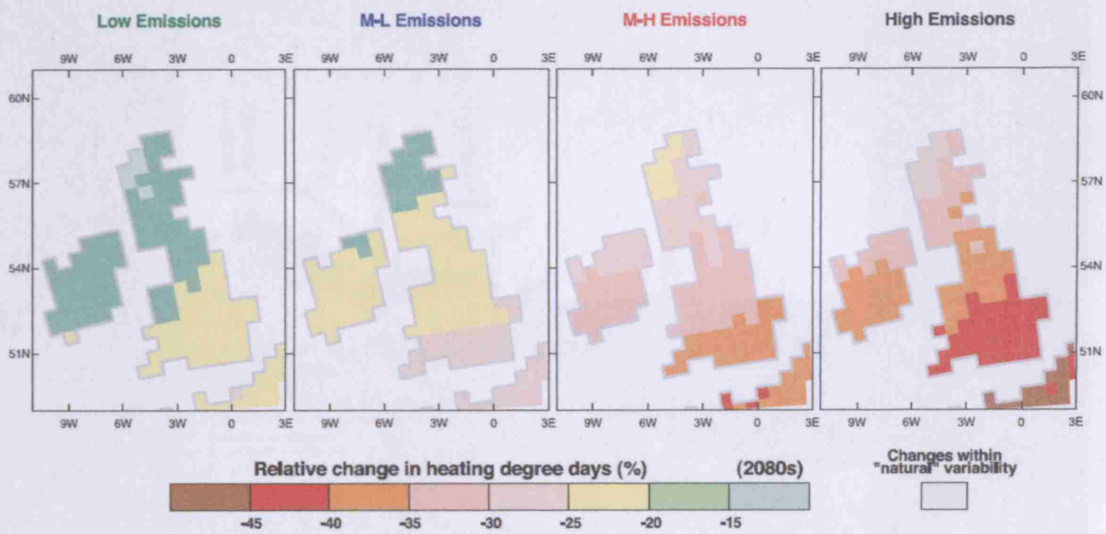

Figure 5: ***Per cent change by the 2080s in the average number of heating "degree days" with respect to the model-simulated 1961-1990 baseline period***

{Source: Hulme, M., et al, (2002)}

[15] UKCIP02 Scientific Report, Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK

2.6 Carbon Emissions

After CO2 is emitted in the atmosphere, it will remain and enhance the greenhouse effect until it is absorbed back mainly by oceans and growing vegetation. The carbon cycle has been studied intensively and the carbon sequestration is well-known. (Figure 6)

If the emission is based near a carbon sink then CO_2 can be accumulated within four years, but usually this is not the case since anthropogenic CO_2 emissions are close to denser populated areas where carbon sinks are scarce. There have been many suggestions regarding the lifetime of CO_2 in the atmosphere, ranging from 50 to 120 years. For this study it is assumed that 100 years would have been a good estimate.

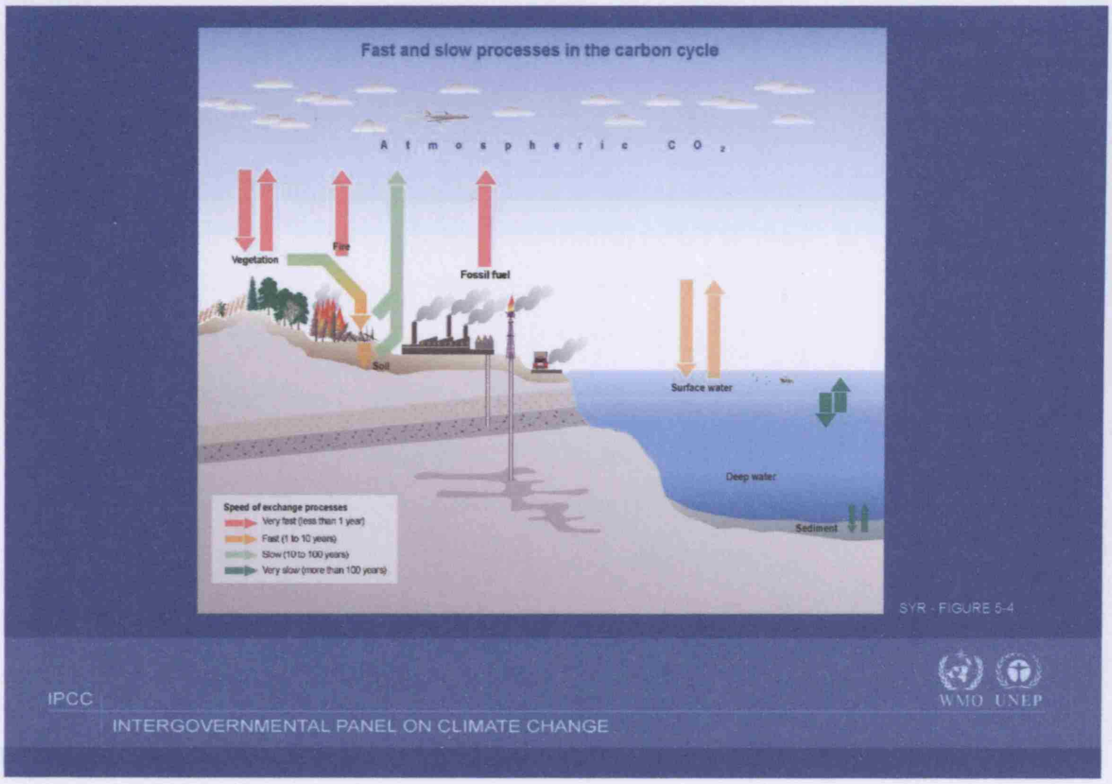

Figure 6: The carbon cycle {Source: The IPCC02 report}

Assuming that emitted CO_2 will remain an active greenhouse gas for 100 years for the purpose of the study a different weight should be given to early emissions than those emitted later.

There are more reasons for trying to be lower that the projected 550ppm in 2050. Accelerated global warming due to carbon cycle feedbacks in the terrestrial biosphere, and releases of terrestrial carbon from permafrost regions and methane from hydrates in coastal sediments could jumpstart chain reaction in CO_2 emissions[16]. The newest IPCC report suggests that a limit closer to 450ppm than 550ppm might be necessary to meet a 2°C stabilization limit[17].

Furthermore much of the climate change over the next 30 to 40 years is determined by the historic emissions and the inertia in climate system[18]. Therefore there is a need in adapting to a new climate reality. However the change in the climate of the second half of the 21st century is still subject to emissions that will occur in the years to come.

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16 http://en.wikipedia.org/wiki/Effects_of_global_warming

17 IPCC Second Assessment Synthesis Report

18 UKCIP02 Scientific Report, Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK

3. Methodology

Hypothesis – is the recommended optimal insulation really an optimal if we take into consideration new energy trends and global warming?

In order to find the optimal insulation a simple approach was followed. The parameters that were taken into account were the insulation's embodied energy and the energy required for space heating. Conducting a full Life Cycle Analysis would have meant taking into consideration the whole embodied energy of the building and the total energy throughout the lifetime of building including services and the energy use of the appliances, the energy for the demolition and recycling/disposal of the materials.

This assumption, that energy for space heating is only correlated to the insulation thickness, simplifies the problem while marginally introducing an error.

In the first stage the energy required for space heating was calculated using TAS, a building thermal simulation program that gives realistic data for heating loads.

Afterwards the embodied energy of the insulation was calculated. By doing that we could sum up the energy that the building would consume during is lifetime.

Since our main concern in this paper is carbon and CO_2 emissions all energies were converted to the equivalent CO_2 emitted during the generation of such energy.

Because of the alterations in the fuel mix for space heating energy, different figures had to be used for different periods of time.

3.1 Availability of data

In order to simplify the analysis but still have feasible and comparable results only the insulation thickness in typical masonry cavity wall construction was studied. Two different constructions were tested to provide a wider range of results. The first used mineral wool as insulation while the other one used polyurethane. The different properties of the insulations resulted in different wall thicknesses. While the mineral wool insulation has lower embodied energy than polyurethane the excess width of the wall increased the embodied energy due to the extra materials that where used to cope with the bigger external building envelope. In view of the fact that the energy savings due to reduction of width were comparable to the excess embodied energy only mineral wool was tested since it was thought to be more environmental conscious than polyurethane.

The cavity wall structure consisted of an outer leaf of brick 102 mm and 100mm inner leaf of lightweight block whereas the cavity was partially filled with insulation material and it is considered a typical structure[19]. The insulation material that we chose was mineral wool that is currently widely used.

Mineral wool

Mineral wool properties combine high thermal resistance with long-term stability. It is made from molten glass, stone or slag that is spun into a fibre-like structure. It is considered a good fire redundant compared to other types of insulations while offering good insulating properties (λ=0.038 W/mK).
This was preferred over polyurethane that has greater insulating abilities (λ=0.025 W/mK) mainly because of the lower embodied energy. Additionally polyurethane's production is connected to high energy use and ozone depletion (through HCFC) and is considered non-recyclable. Mineral wool is recyclable, though most of it is usually landfilled at the moment, and may contain a high percentage of recycled material.
Although the great properties, thicker layers of mineral wool will be required to achieve the same U-value as petrochemical derived insulations

[19] Stirling C., Insulating masonry cavity walls, GBG 44,BRE, 2001

3.2 The TAS model

3.2.1 Building form

A readymade TAS model was used[20] that was described as "what BRE classifies as typical UK houses (in terms of area etc.)"

The kind of dwelling that was selected was a detached type because there has been an increase in newly built block of flats (2.3% increase since 1970) and detached buildings (5.6% since 1970) [21] and the latter was more appropriate for this study.

The building is a 2-storey detached dwelling and the floors layout can be seen in Figure 8 and the 3-d model in Figure 7. Whereas the areas of the various rooms can be seen in Table 3

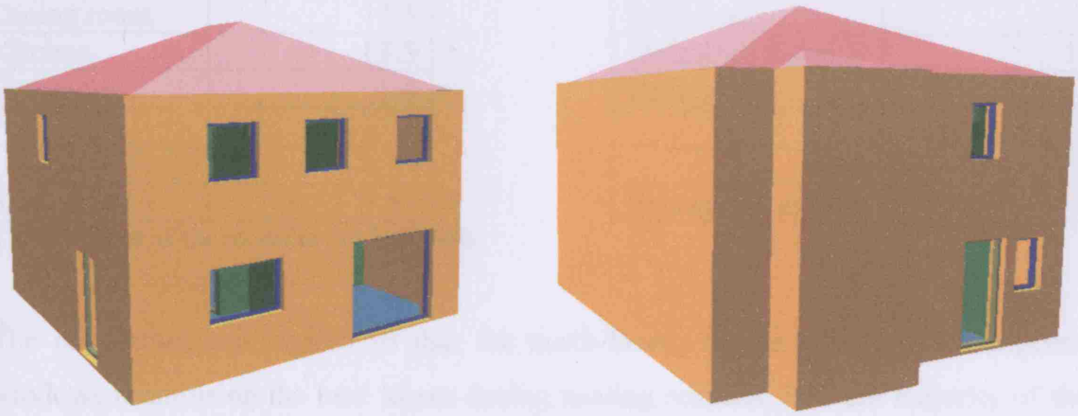

Figure 7: 3D TAS model of the dwelling

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[20] Young A. N., Pathan A., He J., Oreszczyn T, (2006), Domestic Air Conditioning: Occupant Use and Operation Efficiency, Final report to the EPSRC GR/S45423/01

[21] Shorrock L D, J I Utley J I, Domestic Energy Fact file, BR 457, BREPress, 2003

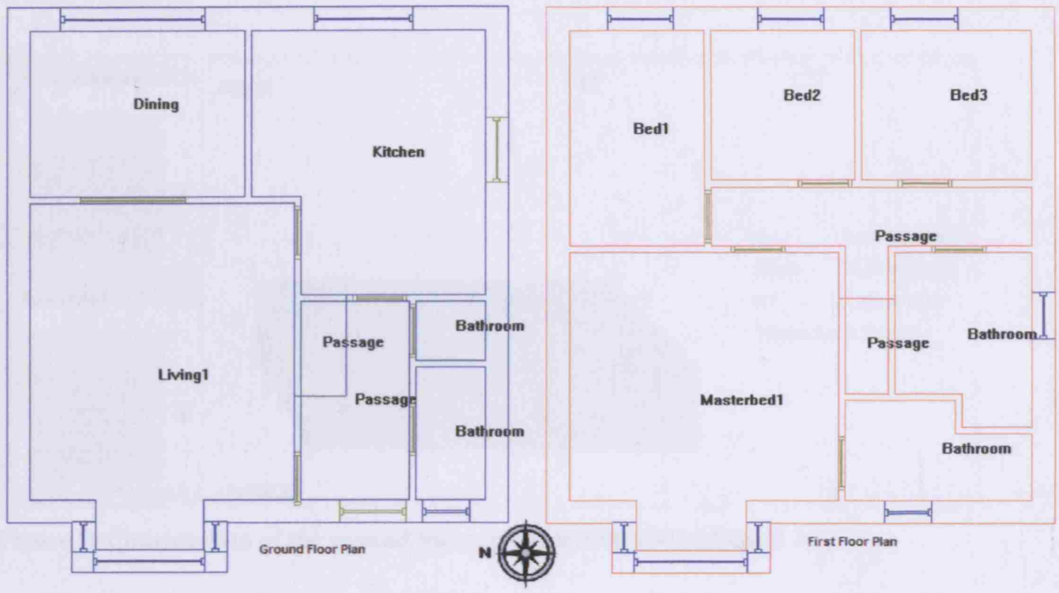

Figure 8: Ground and 1st floor layouts

Room	Area (m^2)
Living room	20
Dining room	12.5
Kitchen	13.5
Bathroom	3
Roof	53

Room	Area (m^2)
Master bedroom	17
Bedroom 1	7
Bedrooms 2 and 3	11
Bathrooms	9
Passages & stairs	7

Table 3: Area of the rooms in the base case.

The orientation was chosen so that the north-facing façade will have no exposed windows minimising the heat losses during heating seasons. Still the majority of the windows are facing mainly east and some west to prevent some overheating during the summer and still utilise considerable daylight. The total living area of the house is $100m^2$ whereas the windows had an area of $16.2m^2$ so the window to floor area ratio was well bellow the limit set by the building regulations to minimise heat losses.

3.2.2 Materials.

The windows were double glazed, low-e with 12mm cavity while the frame was a typical wooden one, 25mm wide. The U-values of the windows were $2W/m^2K$.
The ground floor had a U-value of 0.25 W/m^2K to comply with the regulations and it had a 100mm mineral wool batt for insulation. The construction of walls, floors and windows can be seen in Figure 9 and Figure 10, with their respective U-values.

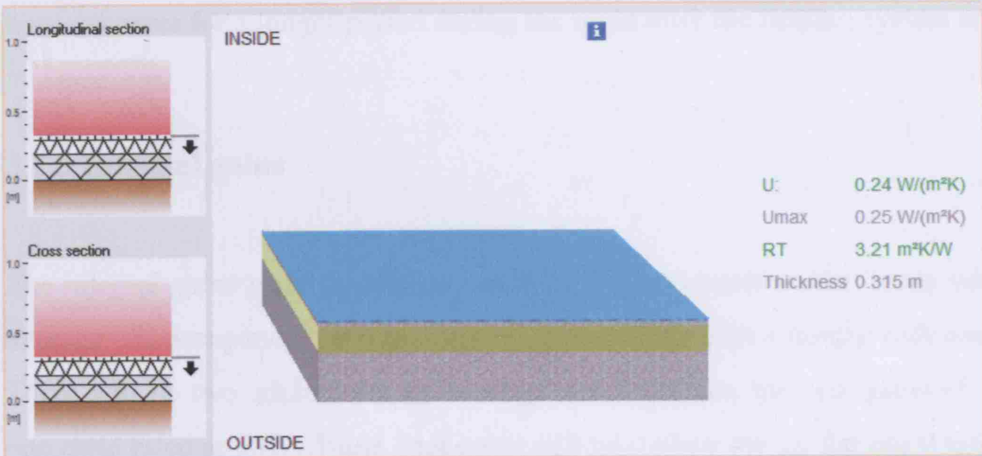

Figure 9: Construction of the ground floor (made with BuildingDeskU 3.2)

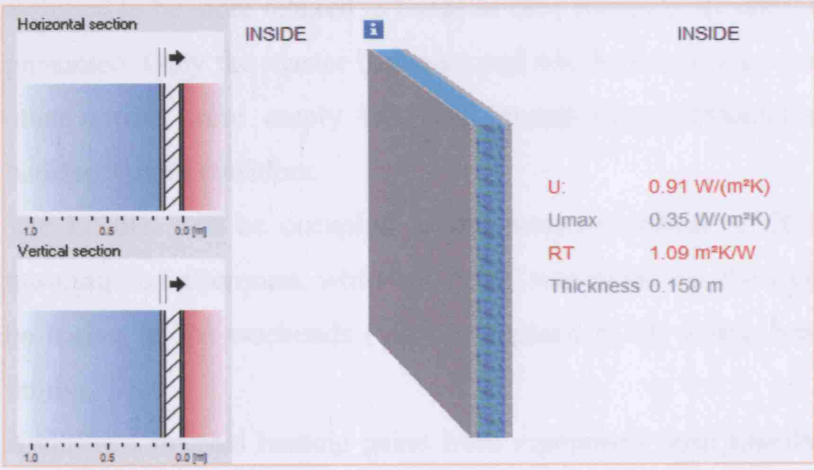

Figure 10: Construction of the internal walls (made with BuildingDeskU 3.2)

Five different U-values of the external wall were set whilst the other building elements were kept constant in order to test only the difference with various insulation thicknesses. The rest of them where set so as to comply with the most recent building regulations of 2006.

The different u-values that were tested were 0.35, 0.25, 0.15, 0.10 and 0.075 W/m^{2}K that were achieved by having mineral fibre insulations of 79, 135, 225, 340 and 500mm thick respectively. Testing insulations with u-values higher than 0.35 were discussed but were discarded following results of test simulations.

A 100mm thick layer of concrete was added after the insulation, on the inner side of the wall, to act as a buffer smoothing out temperatures swings. The role of the thermal mass is to absorb heat and release it during the night so it will help to prevent overheating caused by internal gains during the cooling period. It should also keep the house warmer for a longer period during the night after the heating system is off.

3.2.3 Internal gains

The internal gains were calculated assuming 2.5 occupants in the house which is the average UK occupancy[22] and is also a good assumption for a family with one child. There will be two adults with an average metabolic rate for heat gains of 100w and one child rated at 50W. These heat gains will take place during the night time up until the morning. An adjustment was made to take into consideration weekends that assumed to be more relaxed in terms of time for the occupants so increased gains were presumed. Only the master bedroom and one bedroom were considered occupied, the other rooms were empty but still treated as conditioned spaces, except of the bathrooms and corridors.

The kitchen will be occupied for an assumed period of 6h divided equally in the morning and afternoon, while provision was made for the living room occupancy to be higher in the weekends (10h) (compared to 8h during weekdays), by the whole family.

Additional internal heating gains from equipment used mainly in the kitchen during the morning and the afternoon hours due to cooking, and in the living room for entertainment equipment, were included. Lighting gains were included during occupancy assuming energy efficient lights.

3.2.4 Ventilation and infiltration

Infiltration was set at a constant 0.5 ACH for all the rooms which is in compliance with the building regulations. The building would be airtight but still there would be sufficient ventilation to achieve good air quality.

The dwelling was set to be naturally ventilated depending on occupancy control. This was modelled in TAS using a function for the openings that resembles manual

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[22] Census 2001, available online http://www.statistics.gov.uk/census2001/ [accessed September 2006]

opening and closing of the windows. The function used , during the occupied periods, was **zdwom,0,20.0,25.0,27.0,5.0**. The windows would start to open when the temperature is above 20°C and will be fully open when the temperature reaches 25°C. The apertures would close when the temperature exceeds 27°C. The wind speed above which the windows would be shut was set at 5m/s, which despite being low ensures the potential of occupant discomfort and inconvenience due to cold draughts and high wind speed disruption respectively.

For the occupied periods a thermostat was used to maintain thermal comfort. The lower limit for the heating to start was set at 20°C while the upper temperature when the cooling would start was set at 25°C. In this study only heating loads will be analysed but the cooling loads will provide information about overheating.

3.2.5 Weather data

The simulation was conducted using 7 different weather data sets. Meteonom weather data for London of 2002 was used as a baseline for the current weather. This set of weather files came from a previous MSc dissertation by Nataly Haw[23]. Out of the four different scenarios that the UKIPC02 have modelled only the low and high emission scenarios were used. The high emissions scenario would show the building's thermal behaviour for the larger range of temperature fluctuation over the years, while the low emissions scenario predicts the most stable climate. The weather data used were the projected 2020, 2050 and 2080 for the low and high emissions scenarios. The reason for choosing 2002 instead of a more recent one was that this weather data was created based on this year and using a more recent weather data file would not offset the results.

[23] Haw, N., 2002, Impact Of Climate Change On Energy Consumption Of UK Dwellings, Report (MSc).University College London.

3.3 TAS results

The building performed well in all simulated scenarios compared to the average heating demand of the UK stock houses. This is probably due to the fact that it was built to be in compliance with the new building regulations and had internal thermal mass both of which the majority of the existing house stock lacks.

All simulations showed good thermal behaviour of the building since in the treated zone areas the temperature was sustained above 20°C using heat emitters. The cooling was more relaxed but even still the temperatures never rose above 27°C in the living areas. Cooling was provided mainly meant to be provided by aperture openings. When the external conditions were unsuitable the excessive heat was removed with the use of mechanical cooling.

The main results that were taken from the simulations were the annual heating and cooling loads. These were, for each projected climate change scenario, plotted onto a graph.

As shown in Figure 11 and Figure 12, there is a gradual decline in energy for space heating. There is steeper reduction in the first 20 years than in the successive periods. Overall, although the different insulations result in different heating demand reduction, they follow the same trend. This was expected since they are subjected to the same decrease in heating degree-days and all the models were simulated using the same weather data and the same comfort zone[24]. Nevertheless, as the U-value decreases, (and the insulation thickness increases) the amount of energy for space heating is reduced by a lesser extent.

By comparing the two graphs, we can see that in the case of the high emission scenario the trend is more obvious. The gradient is sharper and there is a mild distinction in the different insulations whereas in the low emissions scenario the behaviour is more similar.

[24] A set of ambient conditions that are thermally comfortable for a human person

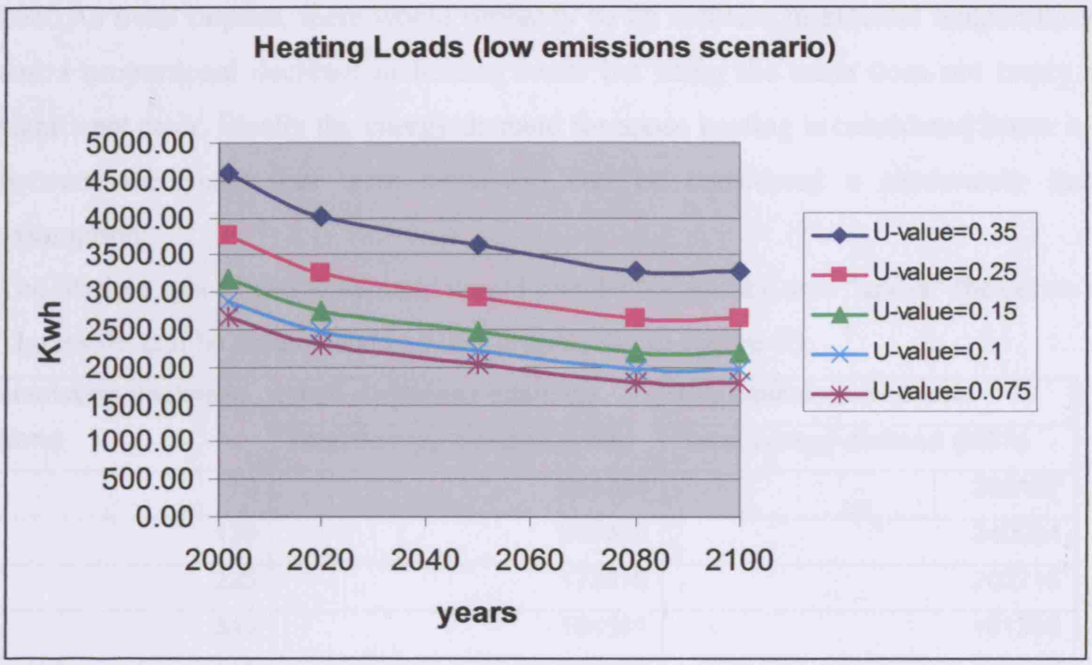

Figure 11: Energy for space heating for different insulations (low emissions scenario)

High Emission scenario

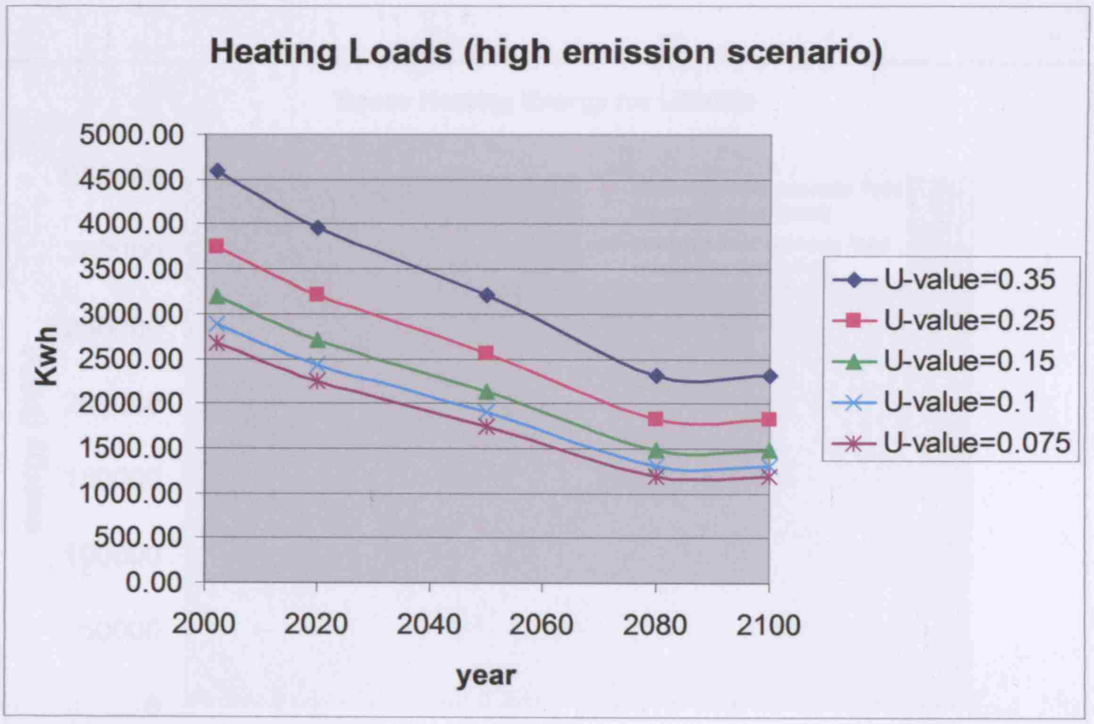

Figure 12: Energy for space heating for different insulations (high emissions scenario)

In order to calculate the energy for space heating during the lifetime of the building (100year) the following assumptions were made. After 2080 since there were not any projected climatic data easily available the space heating load would be the same as in

2080.As trend implies, there would probably be an increase in external temperatures and a proportional decrease in heating loads but using the same does not imply a significant error. Finally the energy demand for space heating is considered linear in-between the years that were simulated can be considered a moderately safe assumption

The lifetime space heating demand would then be the surface area "under" the curve. The results can be seen in Table 4 and graphically in Figure 13.

Insulation thickness (mm)	High emissions scenario	low emissions scenario
	Total energy demand (kWh)	Total energy demand (kWh)
79	258743	298187
135	207466	240904
225	173475	202715
340	154561	181390
500	142064	167279

Table 4: Heating energy demand throughout the life span of the building for different insulation (high and low emissions scenarios)

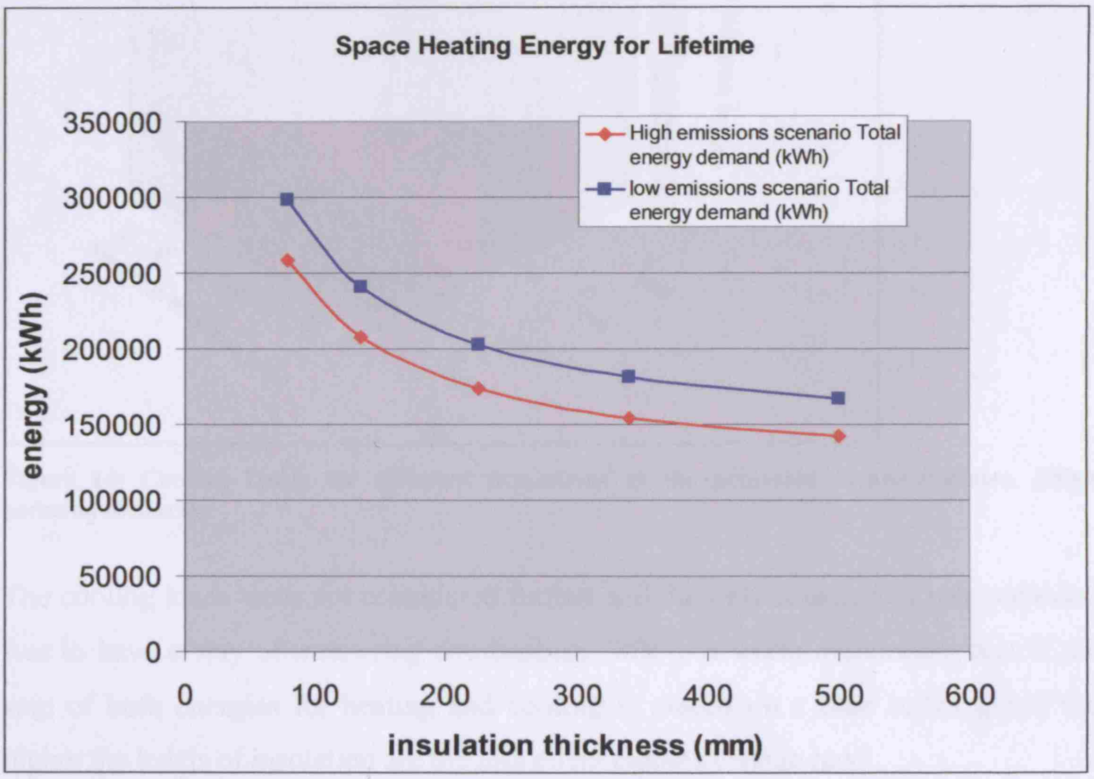

Figure 13: Heating energy demand throughout the life span of the building for different insulation (high and low emissions scenarios)

It is obvious that the energy will continue to decrease if we keep adding insulation. However the savings, in energy, seem to become lower as the insulation thickness increases.

In both scenarios of low and high emissions an unpredicted result came up. The cooling loads would increase with the increase in the insulation thickness. One would expect that extra insulation would help in keeping high external temperatures from heating the building. A plausible explanation is that although extra insulation acts as a heat loss barrier from the external climate, it also acts as a 'blanket' that traps heat inside. This combined with scheduled internal gains and a low infiltration rate could be overheating the building when the insulation is improved.

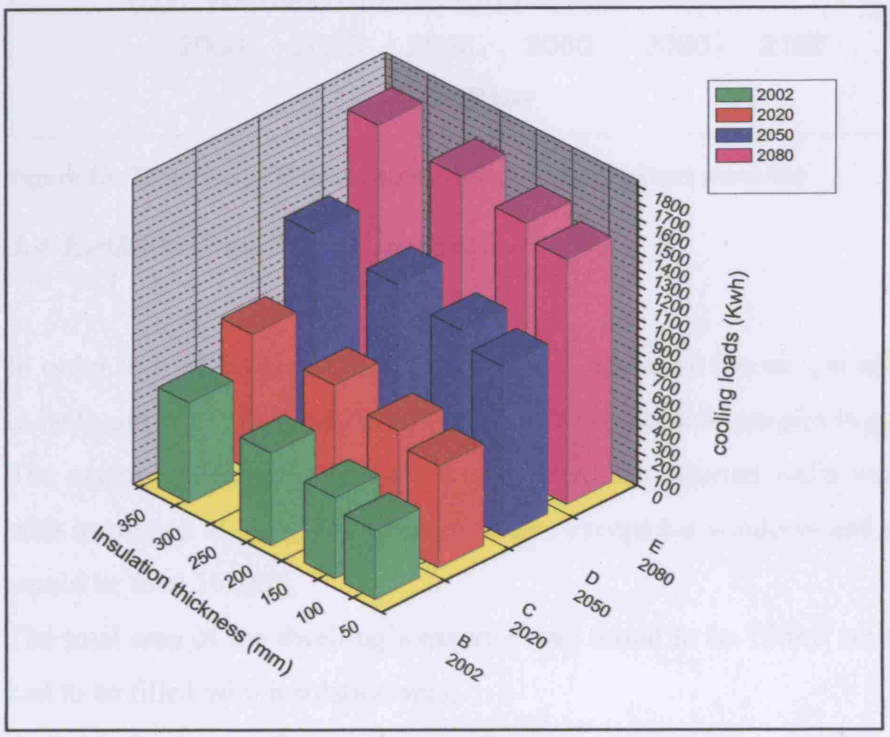

Figure 14: Cooling Loads for different insulations at the projected future climates. (High emission scenario)

The cooling loads were not considered further and the only reason that was provided was to have a way of measuring overheating. Still it is worth mentioning that if the sum of both energies for heating and cooling is placed on a time series graph the higher the levels of insulation are the less effect climate change has.

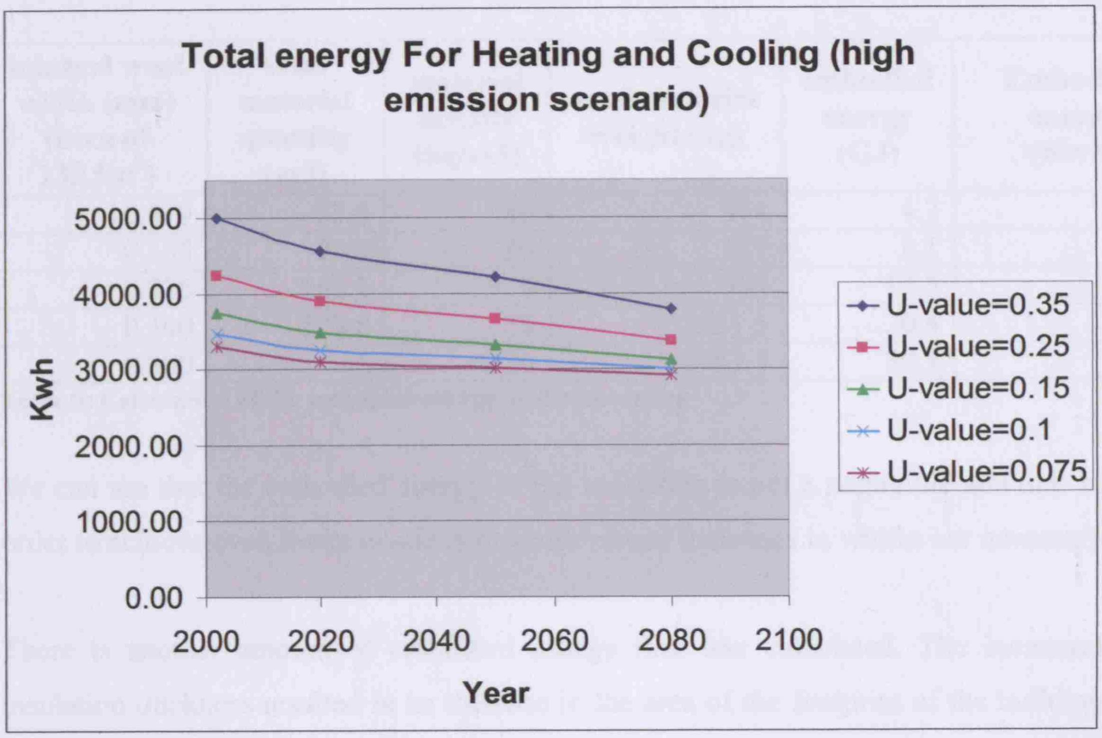

Figure 15: Total energy (heating and cooling) (high emissions scenario)

3.4 Embodied energy of insulation

In order to find the embodied energy of the insulation the weight of the material had to be found since the data that is available for embodied energies is given in MJ/Kg. The assumptions that were made were that all the external walls were partially filled with insulation at the given constant width, except the windows and doors area which would be total 16.2m2.

The total area of the dwelling's exterior was found to be 155m^2 so the total area that had to be filled with insulation was:

$$S = (S_{total} - S_{openings}) \cdot height = 135.2m^2$$

Finding the volume by multiplying each time with the insulation thickness and using the material density gave us the weight of the material that was used. Finding the volume by multiplying each time with the insulation thickness and using the material density gave us the weight of the material that was used. The embodied energy resulted from a multiplication of the weight with a factor of 15.1 KJ/Kg [25] (15.1GJ/tonne). These calculations can be seen in Table 5.

[25] Embodied Energy Data from Environmental Building News (1) for generic type of insulation

mineral wool width (mm) (area of 132.5m²)	total material quantity (m3)	material density (kg/m3)	total material weight (kg)	embodied energy (GJ)	Embodied energy (Kwh)
0.079	53.4	30	314	4.7	1317
0.135	91.3	30	537	8.1	2250
0.225	152.1	30	894	13.5	3751
0.340	229.8	30	1351.5	20.4	5668
0.500	338	30	1987.5	30.1	8336

Table 5: Calculation of the embodied energy of the insulation

We can see that the embodied energy of the insulation is not a negligible amount. In order to achieve even lower u-values disproportional increases in widths are necessary.

There is another amount of embodied energy that was calculated. The increased insulation thickness resulted in an increase in the area of the footprint of the building since we have kept the living area constant (=100m2).

In order to find just the increase in the embodied energy of the whole building due to the energy for excavating building greater volumes that the insulation would have caused a simple assumption was made. The excess area that needed to be built was the insulation thickness multiplied to the perimeter of the building. Still this doesn't take into account the energy building bigger corners or increasing the depth of the foundations and provides no correlation with the height of the building.

This area was afterwards multiplied with the embodied primary energy[26] of a typical new build house in the UK per m^2. Table 6 shows this energy for the different widths of insulation.

Insulation thickness (m)	U-value	excess area (m^2)	embodied energy per m^2 (kWh/m^2)	Total (kWh)
0.079	0.35	2.48	280	686
0.135	0.25	4.18	280	1172
0.225	0.15	6.95	280	1953
0.34	0.10	10.54	280	2951
0.5	0.075	15.50	280	4340

Table 6: Surcharge in the embodied energy of insulation due to increase in wall thickness

[26] Embodied Energy In Residential Property Development, Sustainable Homes available online [http://www.sustainablehomes.co.uk/pdf/Embeng.pdf] [accessed September 2006]

So the total embodied energy that was accounted was the sum of the above energies. This was afterwards converted to CO2 emissions equivalent using the BRE figure of 0.069 KgC/kWh (1996) and multiplied by the factor of 44/12 to covert it from carbon to carbon dioxide. The total embodied energy and CO2 emissions can be seen in Table 7.

Insulation thickness (m)	embodied energy of the material (kWh)	embodied energy surcharge	Total energy (kWh)	Total CO2 emissions (kg)
0.079	1317	686	2003	333.2
0.135	2250	1171	3421	569.4
0.225	3751	1953	5704	948.9
0.34	5668	2951	8619	1433.9
0.5	8336	4340	12676	2108.7

Table 7: Total embodied energy and CO2 emissions for different insulations.

3.5 Carbon neutral energy sources[27]

An important aspect affecting this analysis will be the source of energy used for space heating.

If we assume that the energy use for space heating remains the same, by not taking into account climate change for example or the increase in population and dwellings, still CO_2 emissions may vary if there is another change in the fuel mix. The most influential factors that could potentially reduce carbon emissions would be combined heat and power generation (CHP), renewable sources of energy especially wind, solar, tidal and bio mass, also whether these are implemented at a large scale or locally in microgeneration. Ground heat source pumps may also add "carbon free" heat especially if the electricity needed to run the system is generated by renewable sources..

Around 1% of the energy used for space heating (7.7 TWhth/y)[28] is currently generated from renewable sources and another 8% ((59 TWhth/y)) comes from combined heat and power (CHP) systems.

[27] All the projected data were taken from "Brown A, Maryan P.,Rudd H., Renewable Heat and Heat from Combined Heat and Power Plants - Study and Analysis, 2006, Future energy Solutions" unless otherwise specified

[28] Digest of United Kingdom Energy Statistics, Energy Statistics Publications, 2005

On the other side conventional energy generation from nuclear energy, which is considered carbon neutral, is in turmoil in the UK because the nuclear factory stock is aged and decommissioning has gradually begun. Coal and fossil fuels might take a bigger share in the generation process by time depending on the socioeconomic status. Gas seems, at this point, as the fuel that will be the biggest contributor to the fuel mix for space heating in the future but despite the fact that is a "cleaner" fuel in terms of CO_2 emissions compared to oil and coal there could be uncertainties to supplies in the UK who from 2005 became a net importer of gas for the first time since gas fields were discovered in the North Sea.

3.5.1 CHP

CHP installations can convert, in one single process, up to 90% of the energy in the fuel to electrical power and useful heat resulting in savings in carbon emissions compared with separate generation of electricity and heat.

Current contributions

In 2005 CHP schemes generated 30,340 GWhe of electricity (that represents around 7% of total electricity production in UK) and supplied 63,124 GWhth of heat. The rated power output was around 5700MWe[29] and 12400MWth[30] for electricity and heating power output[31] respectively.

Potential and future projections

To reduce carbon emissions and help deliver the UK's Climate Change Programme, the Government has a target of achieving at least 10,000 MW_e CHP capacity by 2010. If this target is met that could potentially mean an output of around 50 TWhe and 110 TWhth by 2010.

Micro CHP can also reduce carbon emissions. A small Stirling engine installed in a new dwelling can provide reductions of around 11% in emissions. In the Energy white paper it is mentioned that there is a potential of 15GW in microCHP installations in 15 years time.[32]

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[29] Watt electrical (abbr. W_e) is a term that refers to power produced as electricity

[30] Wth: watt thermal is a term that refers to power produced as heat.

[31] Digest of United Kingdom Energy Statistics, Energy Statistics Publications, 2005

[32] MicroCHP addition in savings was not included to the average carbon emission factor

To reduce carbon emissions and help deliver the UK's Climate Change Programme, the Government has a target of achieving at least 10,000 MW_e CHP capacities by 2010.

3.5.2 Biomass

Carbon savings

In the last 20 years many studies were undertaken to find the carbon saving potential of energy crops. In a review of all those studies summed up that there was a 95% saving in almost all cases compared to the carbon from fossil fuel. If biomass fuel is used in CHP generation then the savings are even more impressive.
The net saving of carbon amounts to 73 kg C/MWh compared to using oil to produce heat and 55 kg C/MWh compared to gas.

Projected contribution

Biomass for domestic heating is projected to contribute 18.9TWh/y of "carbon free" heat by 2010 with projections to reach 19.8TWh/y by 2020.

3.5.3 GSHP – Ground source heat pump.

Carbon savings

The carbon savings are 61 kgC/MWh compared to using oil to produce heat and 43 kgC/MWh compared to gas [33] by using GHSP. This savings are taking into consideration the electricity used for running the system.

Current contribution

There is about 5 MWth of installed GSHP in the UK that provide around 30 GWhth of "carbon free" heat.

[33] Brown A, Maryan P.,Rudd H., Renewable Heat and Heat from Combined Heat and Power Plants - Study and Analysis, 2006, Future energy Solutions

"The Barker Review projected that there might be as many as 1 million extra dwellings in the UK by 2020. If a similar proportion of these premises were off the gas grid as at present and had appropriate access to suitable land, which is likely due to the use of green field sites for many housing schemes, this new housing could add a further 160,000 opportunities to the GSHP market, adding a further 2.9 TWh/y to the technical potential, increasing the total carbon saving potential to 3.9MTC/y[33]."
From this figure 25% was projected to be utilised so the carbon savings that could be achieved would be 0.98MTeC/y by 2020.

3.5.4 Renewable Sources

Renewables could contribute an additional 6.0 TWh/y to the heat market in 2010, rising to 34.9 TWh/y in 2020 (equal to 0.8% and 4.7% of total UK heat demand).
This includes solar heating, small scale wind and solar domestic schemes amongst others.
Carbon Savings

Renewable sources are considered "carbon free". The energy related to the construction, operation and decommissioning the equipment needed (e.g. the wind turbines or pv panels) is small related to the energy production during the system life. In addition this energy (and the related emissions) are currently being attributed to the industry section rather than the domestic.

Potential and projected contributions

The 2002 Energy Review set a target of 10% of electricity to be produced form renewable sources, the target was increased to 15% by 2015 and finally in the 2006 Energy Review the longer term goal of 20% by 2020 was set. While this goal was set for electricity it would have an impact on heating either in the way of CHP or by powering up GSHP. Electricity can also be used for space heating with almost 100% efficiency of the delivered energy so if the electricity comes from renewable sources it will be "carbon free" heating.

The renewable energy manifesto was published by 11 leading renewable energy trade associations joining forces and proposing an eight point action plan to expand the use of renewables so as 25% of energy needs.

3.6 Carbon Factor model

The carbon emission factors of different fuels is conventionally expressed in terms of carbon emitted per unit of delivered energy (KgC/kWh) and depends on the different fuel composition and the efficiency of the technology to harness energy.
For heating fuels the emission factor is calculated as KgC/kWh of delivered energy in form of heat of the fuel, irrespective of the efficiency of heating devices.
In order to convert the future energy consumption for space heating due to the fluctuating fuel mix an average carbon emission factor was modelled and applied to the total of the energy used for domestic space heating.
Over the calculations of the embodied energy of the insulation (and the energy surcharge for bigger building forms), the figures that were used were the current emissions factors. For the embodied energy of the insulation this factor is given in KgC/tonne of material and summarises the energy used for excavation, collection and manufacturing energy costs. It does not currently include the energy for transportation of the material.

<u>Current Fuel Mix</u>

The current mix of domestic heating fuels is taken to be 5.9% electricity, 78.8% gas, 8.2% oil and 6.0% solid based on BRE data. [34].

The carbon emission factors, current and projected where taken from the Market Transformation Program and for the current situation are

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[34] Energy Efficiency Standard of Performance, 2002-2005, DEFRA, UK, available online [http://www.defra.gov.uk/environment/consult/energy/per2000/05.htm accessed September 2006]

Fuel	Gas	Oil	Electricity	Solid[35]
Emission factor (KgC/kWh)	0.053	0.072	0.111	0.043

For gas the carbon factor is not expected to change much over the years since the percentage of methane (CH_4) in natural gas is relatively unchanging, there is a mild fluctuation for oil but averagely it can be considered as invariable without a great margin of error. As for electricity there has been a considerable improvement in the efficiency of the production technology over the last 30 years (0.290 KgC/kWh to 0.111 KgC/KWh[36]) but using the same emission factor, as today, for the future will not deviate our results due to the low percentage and the declining trend of electricity-based heating. Furthermore such another increase in overall efficiency is may not very likely be observed. The Market Transformation Projects the emission factor for electricity to drop to 0.107KgC/kWh in 2020, while in the 40% House project by Oxford University there is a forecast for 0.1 KgC/kWh for the period 2030-2050.

Methodology

In order to assess the CO_2 that the delivered energy would emit, carbon emission factors where used for each of the different forms of delivered energy. This factors where given[37] in KgC/KW and afterwards where converted from Carbon to Carbon Dioxide by applying the factor 44/12 (i.e. 1Kg of Carbon is equivalent to 3.66Kg of CO2)

The gas and oil emissions factors where assumed constant for the whole period of 100 years. This assumption is straightforward since neither the carbon content nor the calorific values of the gas and oil[38] are likely to change much in the future.

[35] Average carbon emission factor of domestic coal, like anthracite, and wood, including wood variants as pellets. In averaging the carbon emission factor 50% of solids was considered coal and 50% wood (Coal Market Study summary report, based on DTI Energy Statistics and Energy Trends.

[36] BNXS01: Carbon Emission Factors for UK Energy Use, available online [http://www.mtprog.com/ApprovedBriefingNotes/BriefingNoteTemplate.aspx?intBriefingNoteID=150 accessed September 2006]

[37] Market Transformation Program, Carbon emission factors for the UK energy use, 2005,available online[http://www.mtprog.com/ApprovedBriefingNotes/BriefingNoteTemplate.aspx?intBriefingNoteID=150] [accessed: September 2006]

[38] The average mix of petroleum product (excluding LPG)

The electricity carbon emission factor was for 2005 0.111KgC/kWh projected to fall at 0.107KgC/kWh (kWh of consumed energy). In order to take into account the fuel mix in electricity generation the factor and the renewables the given number was used but part of the electricity was assumed as carbon neutral.

The whole period of 100 years was divided to three periods

i. 2000-2010
ii. 2010-2020
iii. 2020-2050
iv. 2050-2100

There are projections about the availability and carbon emission factor for the 1st period and three scenarios were modelled for the 2nd and 3rd period Owing to the unpredictability of the future in energy fuel mix and emission factors for the 4th period the fuel mix and emissions factors where considered constant and were taken at the levels of 2050.

The average carbon emission factor was calculated using the following assumptions. We already know the total energy use in the domestic sector. From that figure 60% can be accounted for space heating and 25.5m houses contribute to that factor. There is a projection of about 180,000 new dwellings per year in UK[39]. This is going to increase the total energy consumption. The assumption that was made was that the energy for each new dwelling will be the average energy consumption of the total stock of dwellings. So each year the total energy will rise by an increment of 0.18m/25.5m of the total current energy use. This average figure masks a huge variation in actual energy consumption in individual properties (and corresponding CO_2 emissions) especially since new buildings that should be accounted use less energy for space heating than old, non insulated ones.

The set of actions, that are going to be taken to reduce carbon emissions, are usually given in terms of carbon savings per year or predicted energy potential. If the carbon savings per year are taken out of the total carbon emissions from space heating (provisioning for increase in new dwellings) then an average carbon emission factor can be estimated as the fraction of the total projected carbon emissions to the total energy.

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[39] UK Energy and CO2 Emissions Projections, July 2006

This is going to be done for three different scenarios, similar to the ones described by the Market transformation projects that will be:

i. *Best case Scenario*: indicates what could happen if the potential is fully exploited to a feasible degree

ii. *The most probable Scenario*: estimates the effects of an ambitious but feasible programme of policy measures.

iii. *Reference Scenario*: estimation and aggregation of the impact of existing policy measures

In details the parameters that were used to model each scenario are:

For the Best case scenario all the potential UK has in reducing carbon emissions will be used to the extend that the market can. This includes savings in carbon emissions because of CHP, GSHP, biomass and the rest of renewable energy sources will be achieved at the projected extend until 2020. After 2020 because the instability of the energy sectors an analogous increase as the energy demand will be applied to these schemes. The assumption for the best case scenario will be that the carbon savings will continue to rise, to a lesser degree than before, but it will still be more than the increase in energy demand due to the increased number of dwellings. There will be an increase by 10% in carbon savings compared to 7.2% in energy demand for space heating. This might not take account of optimistic schemes to reduce carbon emissions but still provides a proportional raise of their share in the fuel mix reducing the average emission factor. After 2050 the average emission factor will remain constant to the level it has reached. This assumption was done for all three scenarios since no projections can be made so far in the future.

The 2nd scenario that might be considered the most probable because it allowed for carbon saving policies to be implemented to an extent, but made provision of the hindrances due to economic aspects of employment. Up until 2010 the measures that were announced were considered to have been put in effect reducing carbon as much as in the best case scenario. In the period between 2010 and 2020 the carbon savings will be two thirds of the best case. In the period of 2020 to 2050, the rise in carbon savings will be less than the rise in energy demand, meaning that more actions will be taken but the same in the fuel mix cannot be maintained. The same average carbon emission factor will be taken for the period of 2050 to 2100.

In the worst case scenario, where all actions are blocked partly because of the economic burden to the market only the measurements up to 2010 will be implemented fully. The period of 2010 to 2020 will only have 1/3 of the best case scenario's carbon savings and for all the other years a constant carbon factor will be taken. Taken the above into account, all the figures were placed in tables for each scenario from where the average carbon emission factor was taken in each scenario.

BEST CASE			
Year	**energy domestic space heating Gwh**	**emitted carbon weight MTeC**	**average carbon emission factor (KgC/kWh)**
2000	327966	18.77	0.05723
2010	351579	17.52	0.04983
2020	376893	15.74	0.04176
2030	404029	16.87	0.04176
2040	433119	18.09	0.04176
2050	464304	19.39	0.04176
2060	497734	20.78	0.04176
2070	533571	22.28	0.04176
2080	571988	23.88	0.04176
2100	613171	25.61	0.04176

Table 8: Average Carbon emission factor calculation (Best Case scenario)

MEDIUM			
Year	**energy domestic space heating Gwh**	**emitted carbon weight MTeC**	**average carbon emission factor (KgC/kWh)**
2000	327966	18.77	0.05723
2010	351116	17.49	0.04983
2020	375901	16.92	0.04500
2030	402435	18.22	0.04528
2040	430842	19.37	0.04495
2050	461255	20.58	0.04461
2060	493814	22.44	0.04544
2070	528671	24.44	0.04622
2080	565989	26.57	0.04695
2090	605941	28.86	0.04763

Table 9: Average Carbon emission factor calculation (Medium Case scenario)

WORST			
Year	**energy domestic space heating Gwh**	**emitted carbon weight MTeC**	**average carbon emission factor (KgC/kWh)**
2000	327966	18.77	0.05723
2010	351116	17.49	0.04983
2020	375901	18.12	0.04822
2030	402435	23.03	0.04822
2040	430842	24.65	0.04822
2050	461255	26.39	0.04822
2060	493814	28.26	0.04822
2070	528671	30.25	0.04822
2080	565989	32.39	0.04822
2090	605942	34.67	0.04822

Table 10: Average Carbon emission factor calculation (Worst Case scenario)

3.8 LIMITATIONS

There are many limitations in this analysis mainly to simplify the procedure. Trying to provide all the affiliated aspects would require making more assumptions potentially giving a greater error.

The external wall's insulation was the only thing that was correlated with energy and CO_2 emissions. There are many factors left out that could change results. The purpose of this report was not to conduct a complete Life Cycle Analysis but to focus on two main things, insulation and CO_2 emissions.

In the analysis only space heating is accounted and energy for cooling is not taken into account. Still there would be a substantial increase in energy for cooling and the related emissions.

Energy trends are affected easily (fossil fuels crisis and/or availability) so projecting into the future of energy is uncertain. Using 3 different scenarios covers only the part of the future fuel mix.

Urban heat island effect is not modelled into the climate scenarios and could change the heating but mainly the cooling loads especially if the population density increases with time.

The change in heating system over the lifetime of the building was not taken into account. By not doing that, savings by using less carbon intensive energy, or excessive emissions due to the downgrade in energy source, were not taken into account.

4. Finding optimal insulation thickness

4.1 Optimise for energy (space heating and embodied energy minimum)

As a first approach, to prove consistency with previous studies, the optimal insulation thickness for less energy was sought. The embodied energy of just the insulation was added to the lifetime energy for heating. In Figure 16 and Figure 17 we can see that the total energy curve is declining. Although there isn't enough data to have a clear view, it was thought that the total energy was exponentially decaying. An exponential fit was observed for both scenarios (low and high emissions) that strongly followed the energy trend.

It was expected that at some point of adding additional insulation, the energy would, start to increase, but this was not observed. If the thickness was increased more than the embodied energy of the insulation, the costs would exceed the savings in space heating energy. This point was not reached in the simulations.

Since the exponential decay fit described the energy behaviour, it could be assumed that the point where adding more insulation will have no effect in total energy consumption is 5 times the decay constant. More specifically, for the low emission scenario the "optimal" insulation would be 471(±35) mm whereas for the high emission scenario this would be 467 (±40)[40] mm.

[40] The error margin is automatically calculated by the software that was used for the fitting (Microcal Origin 7)

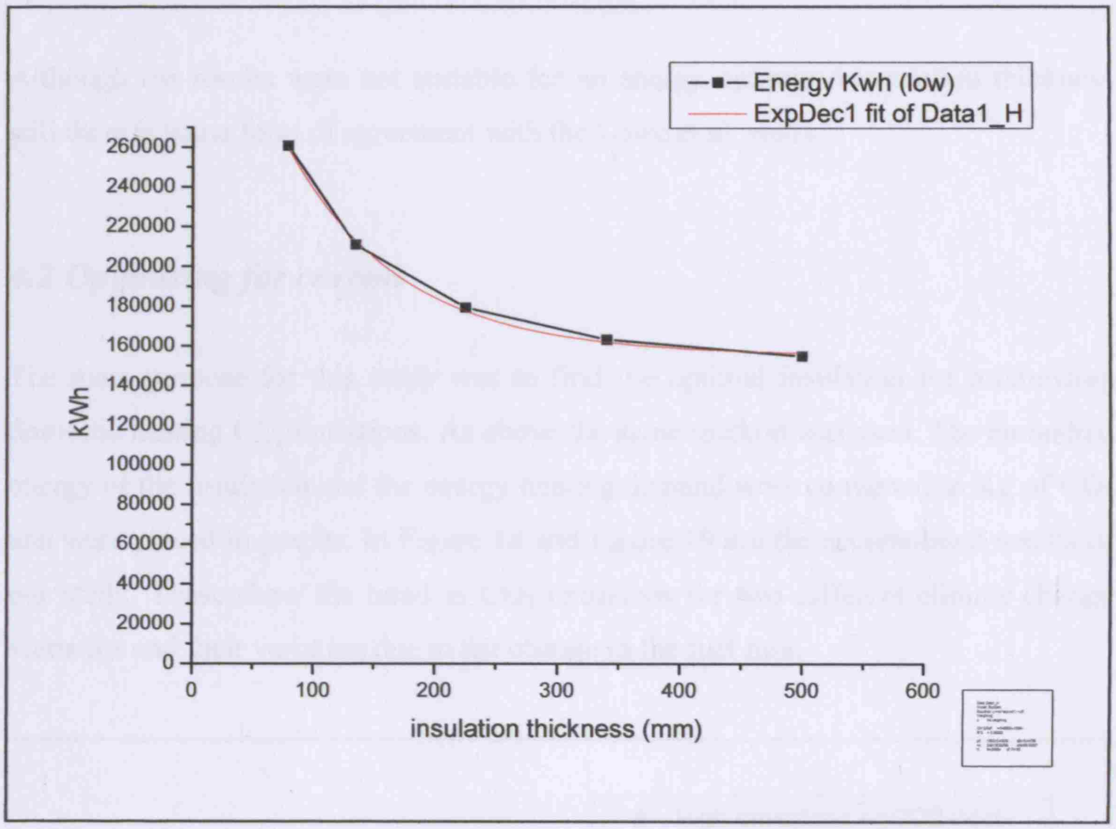

Figure 16: Optimising for energy, optimal insulation thickness. (Low emissions scenario)

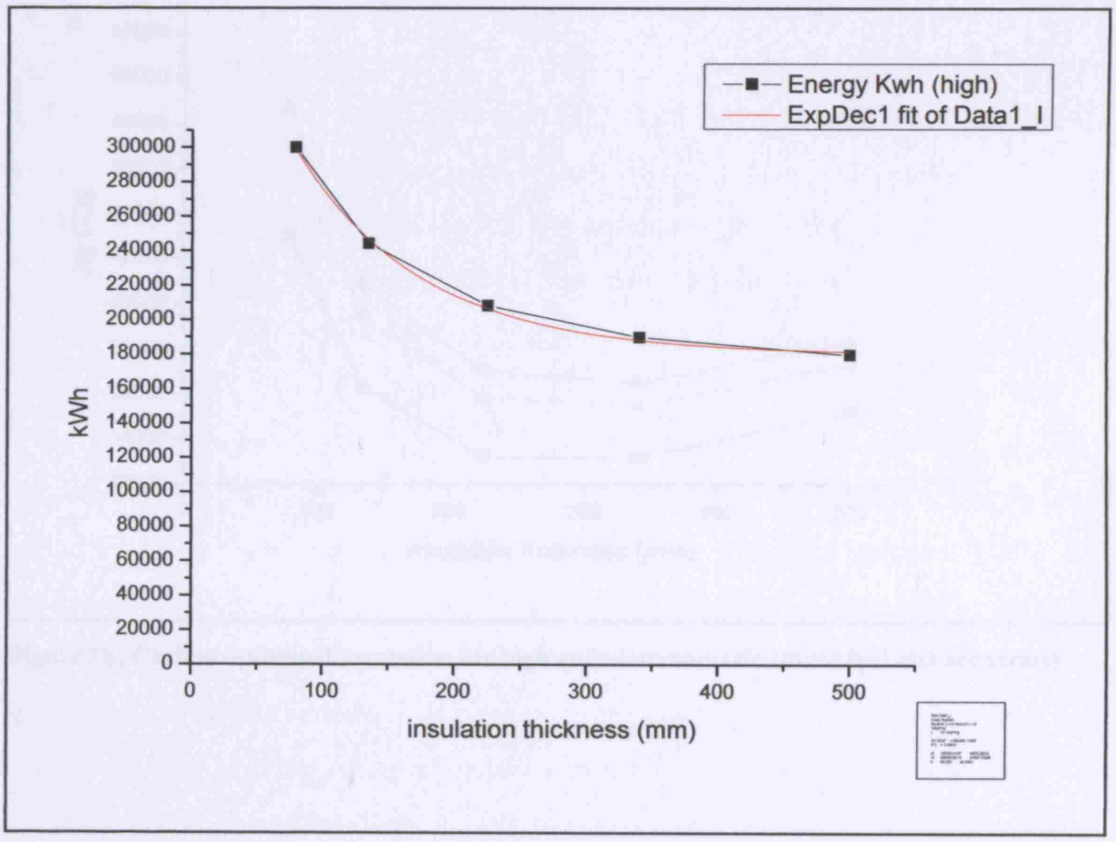

Figure 17: Optimising for energy, optimal insulation thickness. (High emissions scenario)

Although the results were not suitable for an energy optimised insulation thickness still there is some form of agreement with the Lowe et al. study.

4.2 Optimising for carbon

The main purpose for this study was to find the optimal insulation for minimising domestic heating CO_2 emissions. As above the same method was used. The embodied energy of the insulation and the energy heating demand were converted to Kg of CO_2 and were placed in graphs. In Figure 18 and Figure 19 are the accumulated results of our study. These show the trend in CO_2 emissions for two different climate change scenarios and their variation due to the change in the fuel mix.

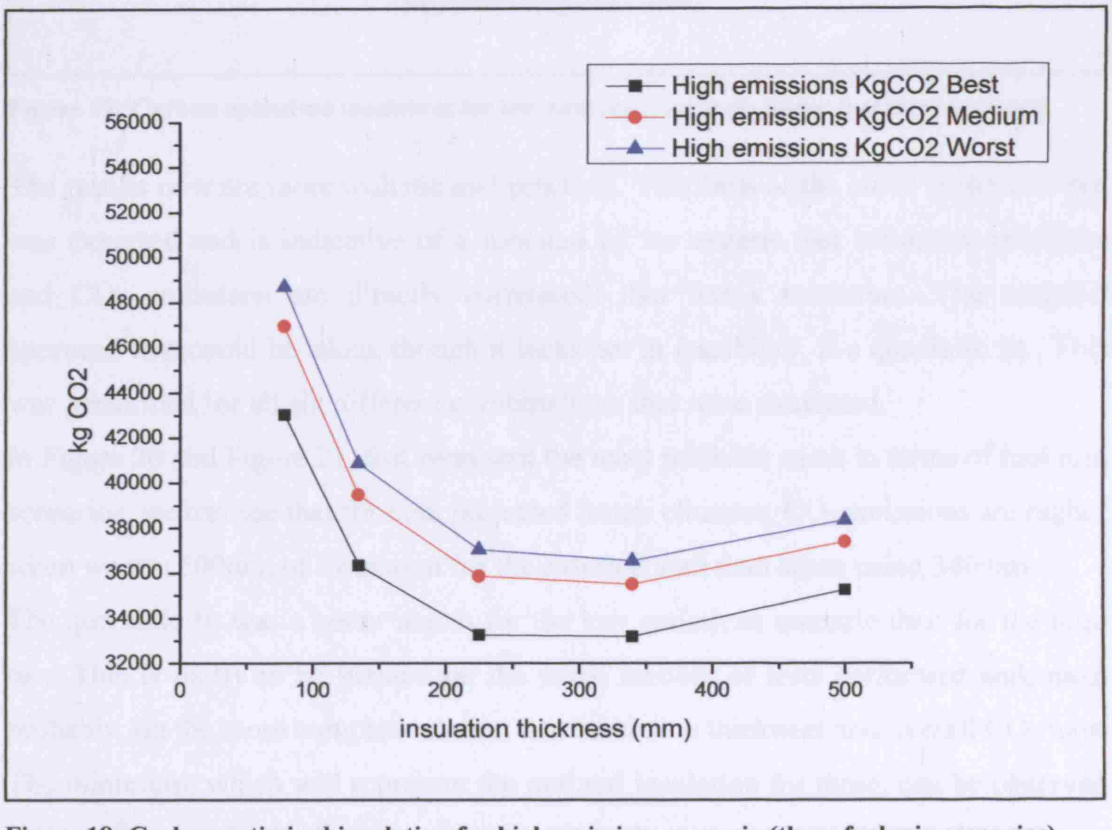

Figure 18: Carbon optimised insulation for high emissions scenario (three fuel mix scenarios)

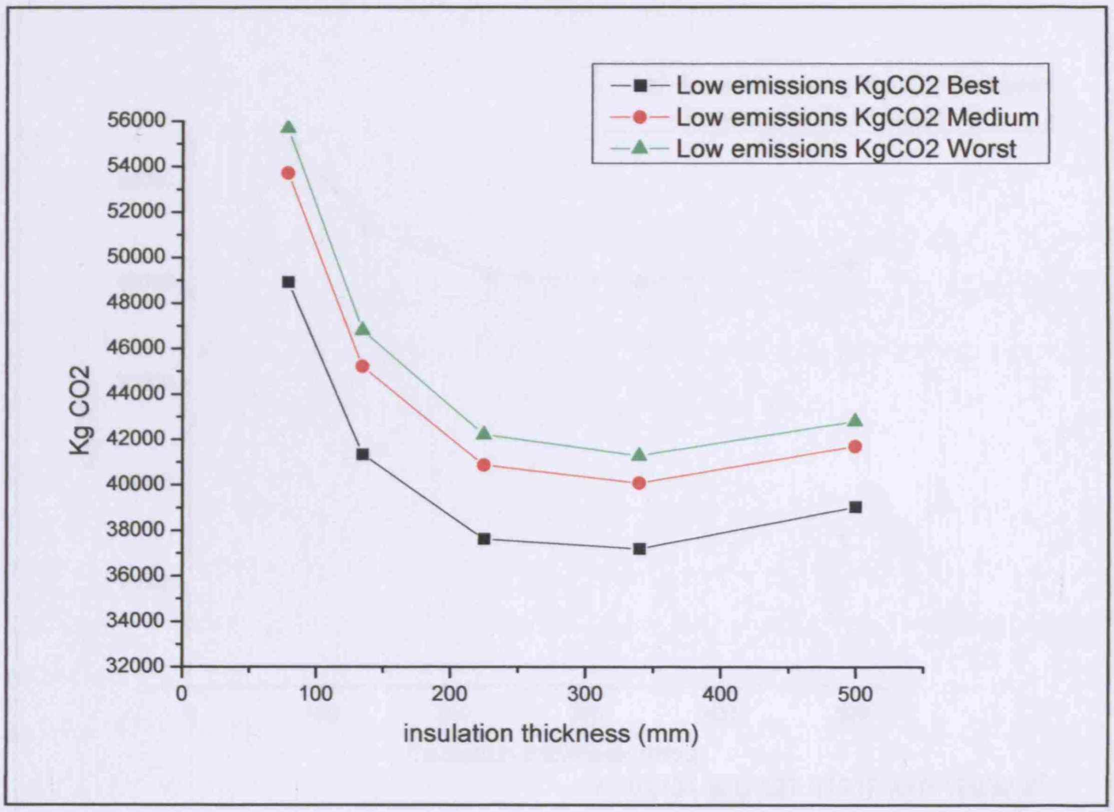

Figure 19: Carbon optimised insulation for low emissions scenario (three fuel mix scenarios)

The results now are more realistic and practical. The form of the curve is the one that was expected and is indicative of a function (if we assume that insulation thickness and CO_2 emissions are directly correlated) that has a minimum. The simplest approach that could be taken, though it lacks not in feasibility, is a quadratic fit. This was performed for all six different combinations that were simulated.

In Figure 20 and Figure 21, that represent the most probable cases in terms of fuel mix scenarios, we can see that for both projected future climates, CO_2 emissions are higher when we use 500mm of insulation for the external wall than when using 340mm.

The quadratic fit was a better match for the low emissions scenario than for the high one. This is partly to be blamed on the small number of tests performed and, most probably, on the more complex relation that insulation thickness and overall CO_2 have. The minimum, which will represent the optimal insulation for these, can be observed very easily graphically, but a more accurate result can be extracted from the equation of the curve (this can be seen on the bottom right side of each figure).

The minimums and maximums of any polynomial are the solutions of the derivative. So for the low emissions-medium fuel mix scenario the optimal insulation will be $S_{opt} = (-b/2a) = 355mm$ and for the high emissions scenario we get S_{opt2}=346 mm.

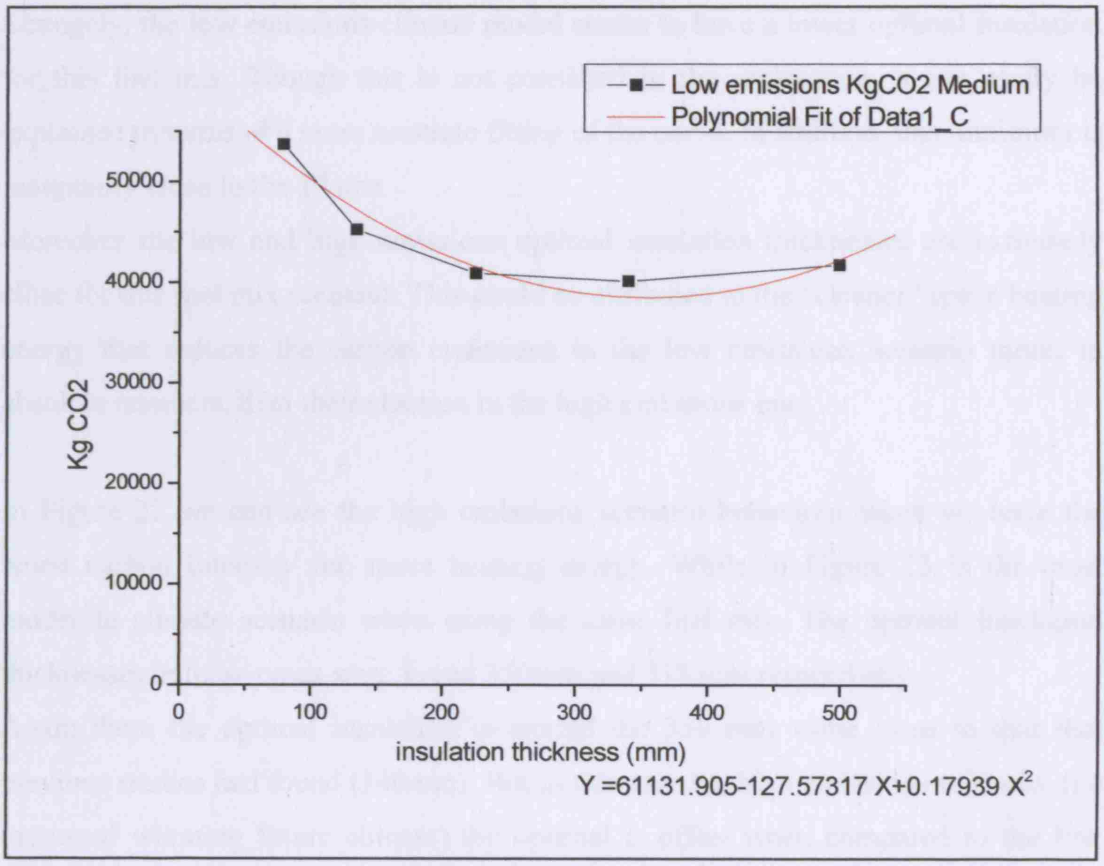

Figure 20: Carbon optimisation, low emissions scenario, medium policy implementation

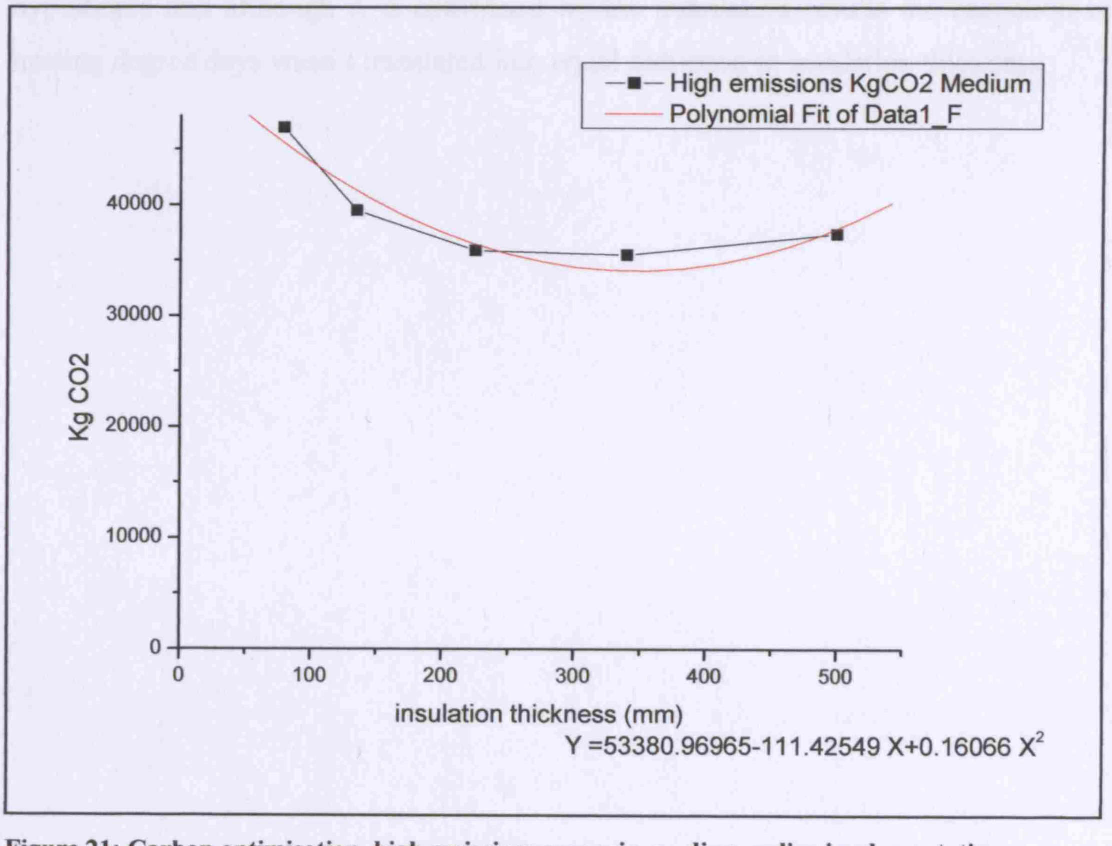

Figure 21: Carbon optimisation, high emissions scenario, medium policy implementation

Strangely, the low emissions climate model seems to have a lower optimal insulation for this fuel mix. Though this is not consisted in the projections, it can easily be explained in terms of a more accurate fitting of the curve. In addition, this minimum is marginally close to the 1st one.
Moreover the low and high emissions optimal insulation thicknesses are extremely close for this fuel mix scenario. This could be attributed to the "cleaner" space heating energy that reduces the carbon emissions in the low emissions scenario more, in absolute numbers, than the reduction in the high emissions one.

In Figure 22 we can see the high emissions scenario behaviour when we have the worst carbon intensity for space heating energy. While in Figure 23 is the most moderate climate scenario when using the same fuel mix. The optimal insulation thicknesses in these cases were found 350mm and 358 mm respectively.
Again there the optimal insulation is around the 350 mm value close to that that previous studies had found (340mm). But in this case the high emissions scenario, (i.e. increased warming future climate) the optimal is offset when compared to the low emissions scenario (more moderate warming). This was one of the original hypotheses and although it is confirmed by the simulation results the reduction in heating degree days wasn't translated into equal reduction in insulation thickness.

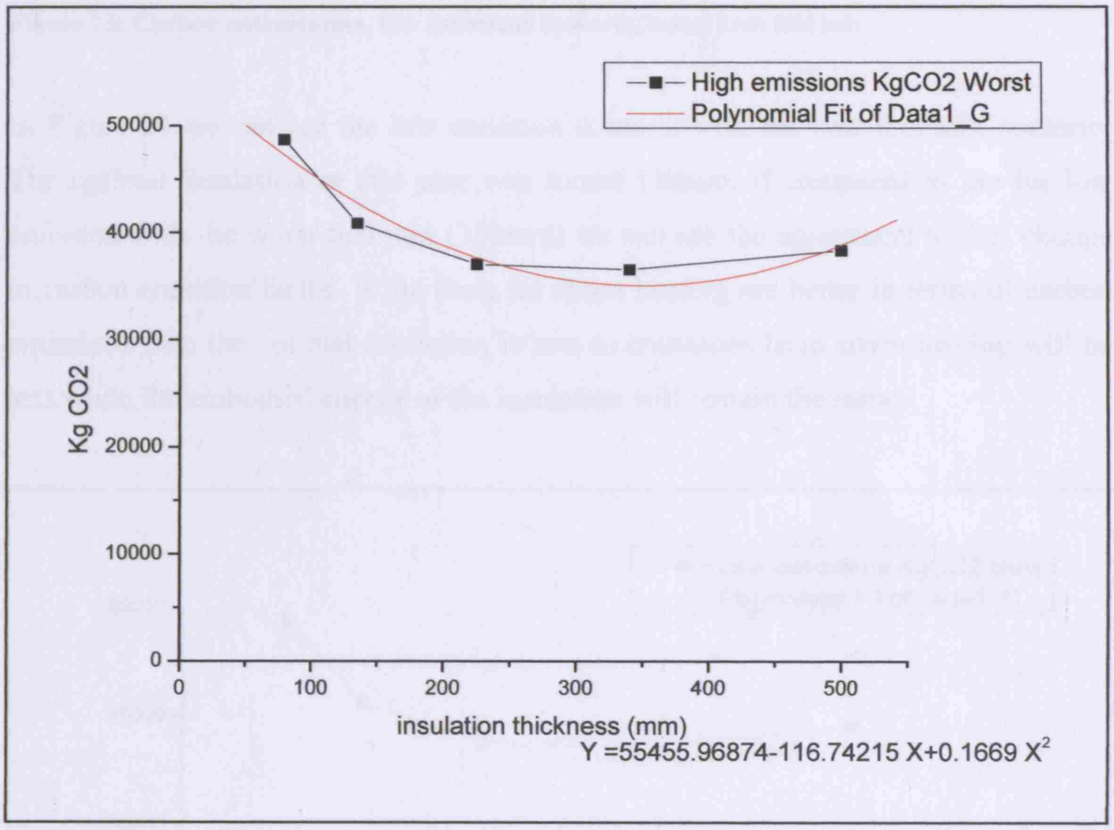

Figure 22: Carbon optimisation, high emissions scenario, worst case fuel mix

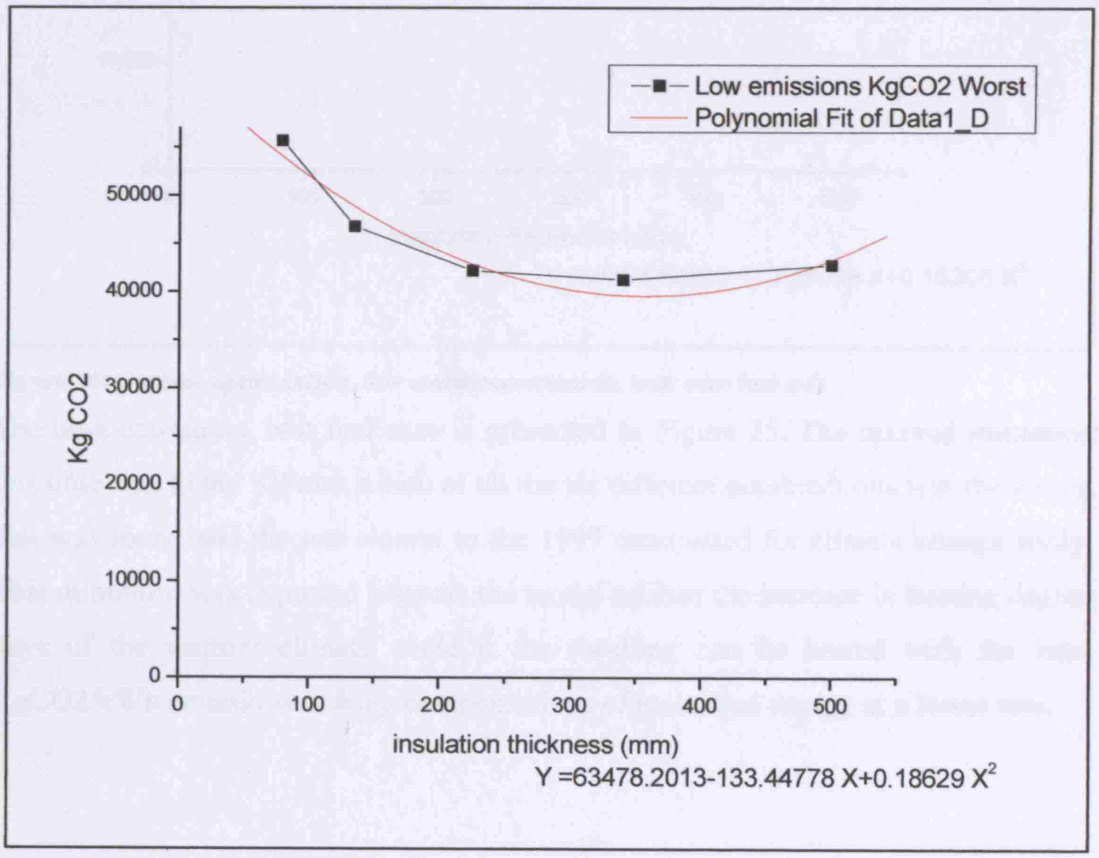

Figure 23: Carbon optimisation, low emissions scenario, worst case fuel mix

In Figure 24 we can see the low emission scenario with the best fuel mix scenario. The optimal insulation in this case was found 348mm. if compared to the for low emission with the worst fuel mix (358mm) we can see the adjustment to the change in carbon emission factor. If the fuels for space heating are better in terms of carbon emissions then the optimal insulation is less as emissions from space heating will be less while the embodied energy of the insulation will remain the same.

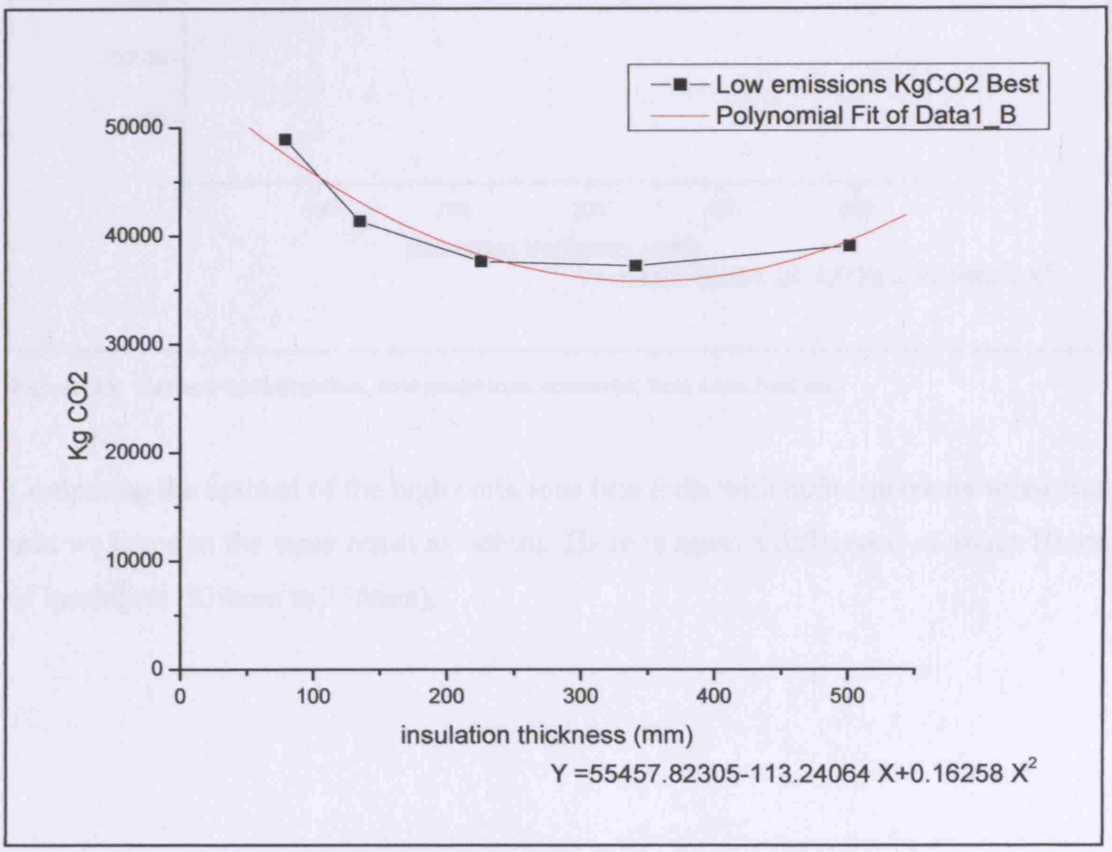

Figure 24: Carbon optimisation, low emissions scenario, best case fuel mix

The high emissions, best fuel case is presented in Figure 25. The optimal insulation this time was found 339mm which of all the six different combinations was the lowest that was found and the one closest to the 1997 unadjusted for climate change study. This minimum was expected because the model utilises the increase in heating degree days of the warmer climate while it the dwelling can be heated with the least KgCO2/kWh emissions making compensations of embodied energy at a lower rate.

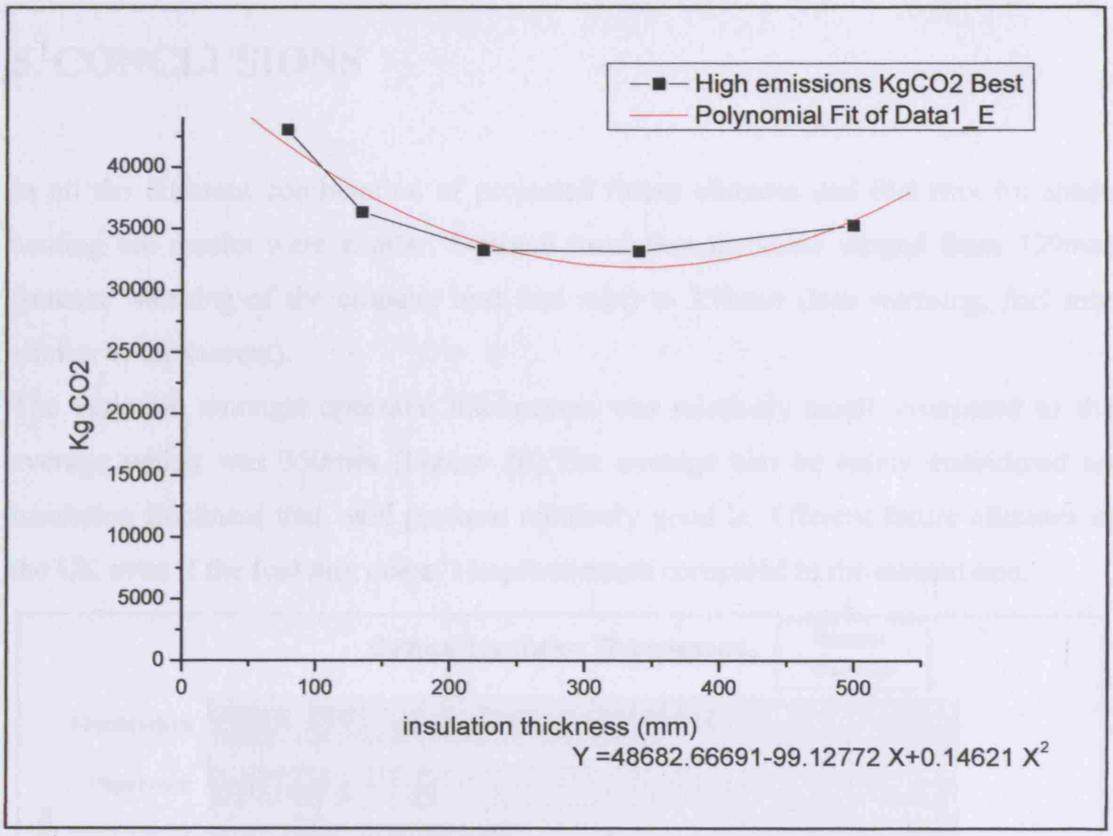

Figure 25: Carbon optimisation, low emissions scenario, best case fuel mix

Comparing the optimal of the high emissions best fuels with high emissions worst fuel mix we come to the same result as before. There is again a difference of about 10mm of insulation (339mm to 350mm).

5. CONCLUSIONS

In all the different combination of projected future climates and fuel mix for space heating the results were similar. Optimal insulation thickness ranged from 339mm (intense warming of the climate, best fuel mix) to 358mm (less warming, fuel mix similar to the current).

The variation amongst optimum thicknesses was relatively small, compared to the average which was 350mm (Figure 26).The average can be safely considered an insulation thickness that will perform relatively good in different future climates in the UK even if the fuel mix doesn't improve much compared to the current one.

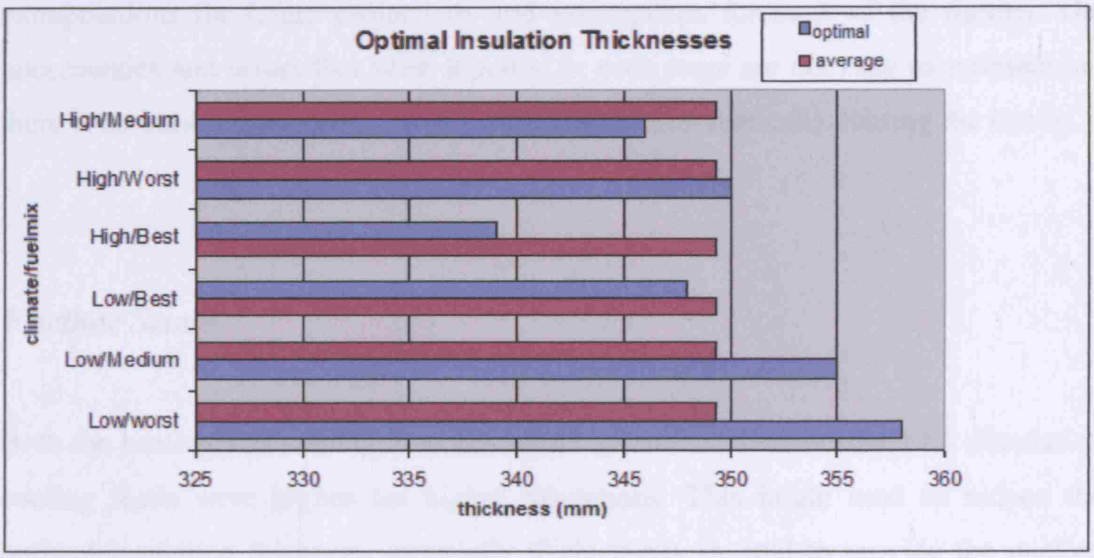

Figure 26: Optimal insulations for all the different scenarios compared to the average.

The fact that the variation is small to marginal, compared to the study by Lowe et al, in 1997, provides little support in the hypothesis that was stated. There is little potential of carbon savings if both climate change and fuel mix and efficiency are put into the equation. Strictly based on the results, installing insulation 350mm thick (mineral wool) in new buildings will have the most benefits in carbon savings in most of the predicted future scenarios.

This level of insulation is hardly used in the UK mainly because of the initial cost; the savings however in CO2 emissions are great and non official standards, such as PassivHaus (which is supported by BRE), are starting to emerge.

Comparing the differences in optimal insulations in these scenarios it can be seen that there is a slight variation in the thicknesses depending on the change in the scenario. The differences between corresponding to the same fuel mix scenario (e.g. good fuel mix, high emissions and good fuel mix, low emissions) are 8 and 9 mm while those corresponding to the same projected climate scenario (high emission with good and bad fuel mix) are 10 and 11mm (taking only the best/worst fuel mix).

In some of the scenarios there might have been a cancellation of the projected changes. For example in the high emissions/worst fuel mix the decrease in energy, due to warming, might have been compensated by the worse fuel mix that resulted in greater quantity of CO2 emissions by average.

It has to be emphasised that reaching to the final results involved making extrapolations for future projections and assumptions for most of the figures. The uncertainties and errors that were inputted in each stage are not easy to estimate but there is no indication that the errors were capable of dramatically altering the results.

Further Study

Both the heating and cooling demands could be studied since in the TAS simulation cooling loads were higher for higher insulations. This might tend to reduce the optimal insulation thickness, especially if electricity is used to provide the cooling load.

These results could be different if the optimal was found based on an economic factor. This would have meant minimising the costs for space heating and insulation. New measurements that could be applied allowing for a specific footprint of carbon per dwelling could shift direction in this study since the cost of emitted carbon surplus or shortage has to be accounted.

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